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Edited for the Council by J. LAURENCE PRITCHARD, Fellow

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NOTICES

Election of Members

The following Members were elected at a Council Meeting on July 6th:—

Fellow.—Mr. E. F. Relf.

Associate Fellow.—Captain A. G. Lamplugh.

Associates.—Mr. L. W. Dove, Mrs. Eliott Lynn, Mr. W. G. Gibson, Flight Lieut. V. P. Feather, Flight Lieut. P. Gaynor-Leigh, F./O. T. B. Prickman, Mr. J. B. Prior, Mr. F. Radcliffe, F./O. J. F. Tadman and Mr. L. D. Whistler.

Student.—Mr. C. D. Perrickos.

Sheffield University

Colonel the Master of Sempill was the delegate of the Society at the coming-of-age celebrations of Sheffield University on July 1st.

Coventry Branch

On the 24th of July a works visit was paid to Messrs. Armstrong, Siddeley Motors, Ltd. Works visits have also been arranged to Messrs. B.T.H. Works, Coventry, for the 14th of August, and to the Whitley Aerodrome on the 28th August.

On Tuesday, July 6th, a film of Mr. Cobham's recent flight to the Cape and back was shown, 180 members of the branch attending.

Library

The following books have been received and placed in the Library:—"Fortschritte der Luftfahrt," by van Langsdorff; "The History and Practice of Aeronautics," by J. Wise; "Turbo-Blowers and Compressors," by W. J. Kearton; "The Science of Flight and its Practical Application," Vol. I.; "Airships and Kite Balloons," by P. H. Sumner; "Balloon and Airship Gases," by C. de F. Chandler; "Aircraft Instruments," by various authors; "Potential-strömung in Ventilen," by B. Eck; "Joseph et Etienne de Montgolfier," by Comte de la Vaulx and P. Tissandier; Second Report of the Adhesives Research Committee; Bulletin de la Société Aérostatique et Météorologique de France, May, 1853; "Compressed Air and Its Machinery," by T. H. Plummer; several Air Ministry publications with regard to the entry into and regulations for the Royal Air Force; "My Flight to the Cape and Back," by A. J. Cobham; "Transport Aviation," by A. Black; "The Metallography of Steel and Cast Iron," by W. E. Woodward; "Aircraft in Commerce and War," by J. M. Spaight; "L'Aviation Commerciale," by O. Bonomo; "Handbook of Instructions for Airplane Designers," by the Engineering Division, U.S. Army Air

Service; "The Movement of Moisture with reference to Timber Seasoning," by S. T. C. Stillwell; "L'Année Aéronautique," by L. Hirschauer and C. Dollfus; Air Ministry Meteorological Pamphlets:—"The Velocity Equivalents of the Beaufort Scale," by G. C. Simpson; "The Absolute Daily Range of Magnetic Declination at Kew," by J. M. Stagg; and "Comparison of Magnetic Standards," by C. Chree; Air Ministry Engine Pamphlets:—A.P. 1158 Condor Engine, Series III.; A.P. 882 Lion, Series II.B Aero Engine; A.P. 1206, Rigging and Maintenance Notes; Bison II., Lion Series V. Engine; Reports and Memoranda of the Aeronautical Research Committee, Nos. 978, 984, 992, 994, 996, 1002, 1003 and 1005; Technical Notes of the National Aeronautical Committee on Aviation of the United States, Nos. 230, 231, 232, 233, 234; Reports of the N.A.C.A., Nos. 216, 219, 220, 222, 224, 225, 227, 228, 230, 231 and 232.

Prizes

The regulations for the Edward Busk Memorial Prize of twenty guineas, and for the R.38 Memorial Prize of twenty-five guineas, may be had on application to the Secretary. Entries for the former must be received by September 30th and for the latter December 31st.

Associate Fellowship Examination

Provided that sufficient entries are received the Society's examination for Associate Fellowship will be held on Monday, September 20th (Part I.), and Tuesday, September 21st (Part II.). Entries must be received by August 23rd at the latest.

J. LAURENCE PRITCHARD, *Hon, Secretary.*

PROCEEDINGS

FIFTH MEETING, SECOND HALF, 61ST SESSION

A meeting of the Royal Aeronautical Society was held in the Society's Library at 7, Albemarle Street, London, on Thursday, March 4th, 1926, when Major G. H. Scott, C.B.E., A.F.C., A.F.R.Ae.S., read a paper on "The Development of Airship Mooring and Handling."

Mr. GRIFFITH BREWER, F.R.Ae.S., who presided in the absence of the Chairman of the Society, in introducing the author, said: Ladies and Gentlemen, I have to introduce to you to-night Major Scott, whom you all know, so it is an easy introduction, but perhaps I may remind you of a few of the great things which he has done. The achievement which stands out in my mind is, of course, the flight across the Atlantic and back again, but before he made that flight he flew up the Baltic, during the time the Armistice was being arranged, and that at the time was the outstanding airship flight. Of course he eclipsed this fine performance afterwards, when he flew to the United States with General Maitland in R.34 and returned. Some of you were present at the dinner given at Prince's Restaurant, when the American Ambassador said that all those who had taken part in the flight were in a position apart from all other men, in having flown to America and back. Although the Atlantic has now been flown in an airship again in one direction, the double record still stands. I am sure that Major Scott did a very great achievement, and raised the prestige of British airship work in setting up a record which has not been beaten yet.

THE DEVELOPMENT OF AIRSHIP MOORING

BY MAJOR G. H. SCOTT, C.B.E., A.F.C., A.F.R.AE.S.

At various times during the last few years, papers on airship subjects have been read before this Society, and in many of these papers the question of airship mooring has been considered, also a very complete history of mooring up till 1921 was read by Flight Lieutenant Butcher in that year.

From 1921 until last year no flying took place in this country, although a considerable amount of experimental work on mast mooring was carried out in America, and there are at present six land masts and one floating mast in existence in America.

During last summer a small amount of flying took place to the original mooring mast at Pulham. During this period from 1921 to date, on two occasions airships have broken away from their moorings—the Shenandoah in 1923 and the R.33 last year. In both cases the airships were able to return to their bases, and in neither case was there any damage to personnel.

Partly as a result of these breakaways, but chiefly owing to proposals to inaugurate an Imperial Airship Service, and the absolute necessity of mooring, if airships were to be a commercial proposition, a good deal of time and thought has been put into this problem.

It is this general consideration of the problem I propose to put before you in this paper. I do not intend going over the old ground, but for purposes of reference a brief history of mast mooring is given in Appendix 1.

Of all systems of mooring, mast mooring is the only system so far tried out that may be looked upon as a permanent mooring system, in that it lends itself

readily to the easy operation and maintenance of the ship while moored, the problem of re-fuelling, re-gassing, being one easily dealt with, and the embarkation or disembarkation of passengers and goods offering no very great difficulty.

It is therefore proposed in treating of mooring to confine this paper to the problem of mast mooring.

There are two separate problems to be considered—the question of riding to a mooring mast, and the question of landing to a mooring mast.

Riding to a Mooring Mast

The question of riding to a mooring mast, although introducing many points of difficulty, is general in its application, as most of the differences in the various types of mooring proposed are in the method of getting to the mast; once on the mast the problem is practically the same for all types.

The question of riding to a mast may again be divided into two sections—first, the aerodynamic forces which act on the airship in bad weather, and secondly the maintaining of the airship in correct static trim under varying weather conditions.

A. This question of the aerodynamic forces acting on an airship while moored to a mast has not until recently received its full share of importance.

In the first consideration of this problem, it was assumed that all the forces acting on the airship were axial, and as a result in the design of the nose of the airship, axial pull was the only one considered. In the R.33 the design was made for an axial load in a wind of 60 m.p.h., and little or no consideration was given to lateral loads, although it was realised that owing to variations in the trim of the airship, the mast may exert a vertical force on the nose of the airship.

It was then discovered that an airship such as R.33, owing to its special aerodynamic characteristics, will not lie stable in the direction of the wind when moored by the nose. It tends to oscillate through an angle which is $4\frac{1}{4}$ degrees on either side of the mean position.

The reasons for this are illustrated in Appendix I. Owing to this phenomenon it is usual to set the rudders at a very slight angle so that the ship shall rest stable at a few degrees off the wind. Vertical oscillations can be checked in a similar manner by keeping the stern of the ship up a few degrees, and it is found as a matter of experience that this is sufficient alone to check oscillations in both directions. It will be seen, however, that an airship riding to a mooring mast in a steady wind is practically always yawed or pitched, and hence a lateral force is introduced, the magnitude of which depends upon the speed of the wind.

This point, although overlooked in the design of the original bow of R.33, was appreciated in the design of the bow of the Shenandoah and also of the new nose of R.33.

When these ships were originally designed, problems in connection with mooring them to a mast had not been considered. It is not impossible, however, to design an airship so that it will not possess those aerodynamic characteristics which cause it to be unstable at the mast and lie off the wind.

It will, of course, be appreciated that it is a much more difficult problem to provide ample lateral strength in the bow of an airship than it is to provide sufficient axial strength.

More recent experience has shown that the lateral forces exerted on the nose of the airship are much more complicated than this consideration alone would indicate, and that the heaviest lateral loads are not necessarily associated with winds of the greatest velocity.

This led to a careful consideration of the subject by the Design Staff of the Royal Airship Works, Cardington.

This consideration was directed towards examining the effects of rapid variations in the velocity and direction of the wind.

In a consideration of this nature the rate of change of direction of the wind and the accelerations of the wind were the new factors introduced into the problem. One of the first difficulties met with was the lack of sufficient meteorological data on these two points.

The records obtained from a single anemometer with an open time scale are not suitable as far as the variation of wind direction is concerned, because the instrument is sensitive to gusts smaller in dimensions than the actual airship and it is impossible to pick out from the recorded curves the rate of variation in the direction of those gusts which are of serious magnitude as far as the forces on the airship are concerned.

As far as recording the variation in the velocity of the wind is concerned, again the records are unsuitable because rapid pressure variations which occur at the head of the instrument are damped out owing to the insufficient diameter of the tubes which connect the head with the recording mechanism.

In order to obtain more reliable information on this question, the meteorological section are proposing to carry out tests with a number of synchronised anemometers set about 600 or 700 feet apart and provided with specially large diameter pressure tubes, from which it is hoped to obtain some basic figures on the structure of those gusts which are of sufficient dimensions to affect the airship. This experiment is of the utmost importance, as without this information it is difficult to estimate the load the bow of an airship may be required to stand while moored.

At the inquiry into the breakaway of the R.33 from the mast at Pulham, one fact of great importance came to light. The bow tube and fittings were sent to the National Physical Laboratory for an examination into the possibility of any distortion, of the axial tube holding the mooring coupling, under lateral load. It was reported that at no time had a lateral force of more than 4.5 tons been exerted on this tube, from which it is possible to say that in spite of the bad weather that this ship rode out in 1921 and in the earlier part of last year, prior to the breakaway, at no time did a combination of conditions of wind arise to produce a lateral force of more than this value of 4.5 tons.

The Design Staff at Cardington, in the investigation referred to above, worked out the lateral forces which the ship would experience from different rates of variation in direction and velocity of the wind. The estimate of 4.5 tons as the maximum lateral force which the ship had ever experienced then served as a means for arguing back to the maximum rates of wind variation which could have occurred.

The methods employed, although admittedly imperfect, were pessimistic as far as estimate of lateral force was concerned, the 4.5 tons representing a possible, though not a necessarily *actual* maximum.

Two simple cases were considered :—

(1) A wind of constant linear velocity changing with constant angular velocity.

(2) A wind of constant direction increasing from zero velocity with constant acceleration, some initial angle of yaw being assumed.

Colonel Richmond will discuss this investigation more fully in his paper which he will read in a few weeks' time, but I may summarise the results as follows :—

It was found that in Case (1), in order to obtain a lateral load of 4-5 tons

in a wind of 30 m.p.h. a rate of change of direction of between three and four degrees per second was required; in a wind of 50 m.p.h. the rate is just over one degree per second.

In Case (2), our 4.5 tons requires for a ten degrees initial yaw an acceleration of 4 m.p.h. per sec. and for a 20 degrees initial yaw an acceleration of between 2 and 3 m.p.h. per sec.

Taking these cases, it is then possible to calculate the forces they would produce on the bow of the new 5,000,000 c. ft. airship, the R.101, and by allowing a very substantial margin over the figure thus obtained, there should be little doubt as to the strength of the bow of the new ship to meet any weather conditions likely to be met with while she is moored.

In all the foregoing it has been assumed that the masthead remains stationary, as any motion of the masthead may under certain conditions produce forces on the nose of the airship in excess of those mentioned above.

If a masthead can oscillate under load, and the equivalent mass moved is large compared with any damping which might occur, and the variation of wind direction or velocity is such as to produce intermittent or alternating forces on the masthead, synchronising with the swing of the masthead, it would be possible to obtain even after one alternation a force considerably greater than that calculated for this gust by the method described.

Although this combination of conditions is not probable, it is by no means impossible, and it is therefore important that the mooring mast should be as stiff as possible so as to prevent appreciable motion of the head.

The new mooring masts erected at Cardington and being erected in Egypt are so stiff that any motion of the top of the mast will be negligible.

But in considering mooring an airship to a mast on a water-borne ship, this possible serious effect of the oscillation of the mast must not be lost sight of.

There is a further point in the design of any mast system which experience has shown to be most important. The airship must be free to rotate about a point on the head of the mast in any direction, *i.e.*, moving about a vertical axis, with change of wind, moving about a horizontal axis with change of trim, and also roll about the axis of the ship herself.

It was largely due to the failure of the rolling bearing that caused the breakaway of the Shenandoah from her mooring mast at Lakehurst, New Jersey.

Further, these three axes of rotation which are at right angles to each other should pass through one common point if complication and excessive weight is to be avoided in the design of attachments.

2. The second consideration in riding to a mooring mast is the maintaining of the airship in correct trim.

It is generally correct to assume that at the normal height at which a large airship will moor, very little can occur in the way of up or down currents except of very small magnitude, in which case they will largely cancel each other over the area of the airship.

The forces, therefore, which tend to make an airship rise or fall while moored to a mast are entirely or almost entirely static, and may be considered as alteration of lift.

Neglecting any question of the loading, unloading, refuelling or gasing of the airship, which can be controlled, or the effect of snow and rain, the only factor tending to alter the lift of the airship while at the mast is the relative alteration of temperature between the air and the gas.

Although it has been found in practice that the air temperature surrounding an airship may vary rapidly, there is a considerable lag in the gas temperature,

owing to the time taken for the gas to absorb or dissipate heat through the outer cover and the layer of air between the outer cover and the gasbags.

Any sudden alteration in air temperature will therefore affect the lift of the airship.

This change may take two forms:—

(*a*) Firstly, a heavy temperature gradient in which there is a decrease of temperature with height.

Any motion of the tail upwards will take it into potentially colder air, and owing to the lag in gas temperature mentioned above, the lift will be increased. Any motion of the tail downwards has the reverse effect, and the airship loses lift.

In each case the alteration of lift tends to increase the motion. Thus the airship may become violently unstable.

It would be difficult to provide any pumping arrangement that could act with sufficient rapidity to deal with a *heavy* temperature gradient. It was for this reason that the artillery wheels were introduced. These consist virtually of weights slung from the airship, shock absorbers being provided in the suspensions. They take the form of wheels so as to offer as small a resistance as possible to the swing of the airship about a vertical axis, with change of wind direction.

The airship is so trimmed by water ballast that about half the weight of these wheels is taken on the airship and half on the ground. Any motion of the airship in a vertical plane tends to transfer the weight of the wheels from the ground to the ship or *vice versa*, thus counterbalancing the alteration in lift of the ship due to temperature gradient.

In order to examine this condition, all available data on temperature gradient are being collected and analysed by the Meteorological Department, and an endeavour is being made to obtain special and continuous readings of the temperature of the air at various heights up a wireless mast in Egypt. If this can be obtained it should give a very clear indication of the maximum temperature gradients to be expected in this part of the world, also a clear idea as to what time of the day they are likely to seriously affect the airship, or what is probably more useful from an operating point of view, the times of the day when no trouble need be anticipated.

A method of calculating the degree of instability in a given temperature gradient and the suspended weight necessary to overcome this is given in Appendix 3.

For any given gradient, provided the wheels are heavy enough, a stabilising effect can be obtained for small motions.

Where an inversion of temperature occurs the airship is naturally stable in the vertical plane, as any motion of the airship will alter the lift so as to decrease the motion. By an inversion of temperature we mean that case where the potential temperature increases with height.

The problem of maintaining the ship in equilibrium while fuelling, or gassing, or embarking or disembarking passengers and goods, is purely a matter of adequate water-ballasting facilities. A number of systems for automatic water ballast control have been proposed at various times and there is no doubt that a suitable system can and will be developed, and will be of great assistance.

All automatic systems depend upon the motion of the airship in a vertical plane for their operation.

(*b*) Secondly, the alteration of air temperature due to alternating gusts of warm and cold air has not so far been observed to be a very serious consideration.

What differences of temperature may have to be faced in the future and

how fast the change from one to another may take place is difficult to say, but although it appears reasonable to assume that where there is little or no wind, the rate of change will not be rapid, and when the wind is strong, even if these changes are rapid, it will be possible to counterbalance the alteration in lift to a large extent by aerodynamic forces.

It is, however, possible that owing to local variations of temperature gradient, the isothermals may vary in height above the ground, and by moving the whole system laterally, the airship may, where a heavy temperature gradient exists, be subjected to alternations in air temperature of a fairly high degree, even with a light wind.

It is hoped the experiments on the wireless masts in Egypt will give some information on this subject.

It is in any case fairly definite that the method proposed for the control of the airships in a temperature gradient, will also be the best method of overcoming any variation in lift due to this second cause of temperature variation.

Until more information is available of the degrees of variation in these two directions, it is not possible to say which will be the controlling factor in deciding the weight of wheels required.

Landing to a Mooring Mast

The problem of landing to a mooring mast consists in bringing an airship that is flying free in the air by mechanical means to a position where the bow of the airship is moored securely to a fixed point on the top of the mast without imposing excessive loads on the airship.

When the airship is first attached to the main hauling wire, and at some distance from the mast, the stability obtained is that of a kite balloon, and practice has shown that as long as this distance is large compared to the length of the airship, no very serious oscillations occur; as this length is reduced, it has been shown by experiment that dangerous oscillations do take place.

It is admittedly difficult to estimate the motion of the airship connected by wires to the masthead. It should also be remembered that little information is available of the variations of the wind likely to be encountered while mooring an airship.

If we take a special case, it is possible in a general way to describe the nature of the motions which may be expected. Assuming the wind to veer, so that the airship is yawed momentarily to the wind direction.

The aerodynamic forces acting on the airship will tend to move the airship bodily sideways, so that the airship and the mooring rope are no longer in the same straight line.

In the case of a water-borne ship where all motions take place in a horizontal plane, the only result is for the ship to ride up slightly to its moorings, its inertia increasing the tension of the rope. In the case of the airship, however, where the rope is inclined, the problem is a three-dimensional one. The effect of this increased tension is to bring the nose of the airship down. The nature of the system is such that yaw involves pitch.

The effect of this pitch may be serious, as its immediate effect is to reduce the dynamic lift of the airship, and in extreme cases the force may be reversed, and tend to drive the airship down on to the ground.

If at the same time, due to the continued change in wind direction, the relative yaw is maintained, it is quite possible to cause disaster.

Further, it is easy to see that this effect, the interaction of yaw and pitch, becomes increasingly more serious as the length of the wire is decreased, and the airship approaches the masthead.

This tendency to violent oscillations as the length of hauling rope is decreased is a common one with kite balloons, and was very clearly demonstrated in the earlier mast mooring experiments. But whereas the kite balloon, owing to its big surplus lift, the quickness with which it swings into the wind and its comparative immunity from damage even with violent oscillations, can be landed on a single wire, it is absolutely impracticable with a large airship.

It therefore becomes essential to check this yaw when approaching the mast, and the only proved method of doing this to date is by the use of side guys.

It has been proposed to overcome this interaction of yaw and pitch by bringing the airship to the mooring mast by an almost horizontal path.

In order to do this, the airship would have to be maintained in perfect static trim and equilibrium, with its height above the ground very little more than the height of the mast.

Owing to the wind disturbances near the ground and temperature variations which may be rapid, apart from the difficulty of ever getting an airship into absolutely perfect trim, the problem set the pilot is an impracticable one, and sooner or later would result in disaster.

Experiments with the use of side guys have shown that once they are taut and provided the angle the side guy makes with the ground is sufficiently small, then the airship can be controlled by these guys right into the masthead, and all dangerous oscillations are prevented.

This necessity of keeping the angle the side guys make with the horizontal plane small necessitates using a large base for the side guys, a radius of 750 feet for the circle of side guy bollards being considered advisable.

Even then, it is obvious that with a strong wind of variable direction it is difficult to prevent one of the guys slacking up and snubbing on the return swing.

In order to reduce this danger a new method of employing side guys has been tested out, the preliminary trials being carried out by using a kite balloon, and later tests being carried out with the R.33.

In principle the method consists in an arrangement of guys which will allow of lateral motion of the airship against a restoring force while the airship is some distance from the masthead, the whole system becoming stiffer as the airship approaches the masthead, and finally reaching the condition of fixed guys by the time contact is made with the masthead.

Thus when the angle of the side guys is large, the motion permitted prevents the possibility of snubbing; as this angle decreases and the tendency to slacken up and snub decreases, the system automatically becomes stiffer.

This prevention of snubbing will enable the side guys to be operated at much larger angles than is the case where fixed guys are used, as it is not essential to completely check all side motion as soon as the guys are attached.

It is also probable that as the side guys exert a damping effect on the motion of the airship, this will prevent oscillations becoming increasingly more serious, and it will therefore be possible to work the side guys satisfactorily on a much shorter base.

This consideration is particularly important in considering the mooring of an airship to a mast on a water-borne ship. If it is possible to reduce this base in dimensions which can be dealt with by a system of booms, the principal difficulty in this form of mooring is solved.

Whatever form of side guys is used when the airship is brought to the masthead by means of the main wire and these side guys, it is still impracticable to bring the nose of the airship to an absolute stationary point, as owing to the

weight and elasticity of the side guys, the nose of the airship is still permitted a certain amount of lateral motion.

It is therefore necessary in the design of the masthead to arrange for the receiving gear on the masthead to follow the nose of the airship through this motion.

Once the airship coupling is locked into the receiving gear, it is then necessary to elastically restrict the motion of this coupling and bring it to the stationary central position to which the airship rides when moored.

This series of operations is necessary so that the airship is secured from the free position to the moored position by a gradual restricting of possible motion, it being essential that all such restrictions are elastic and not suddenly applied forces.

It must always be realised in the design of a mooring system that at any time during the operation a sudden change in wind direction may occur and tend to make the airship move sideways. If sideway motion is permitted, it must be checked gradually and not suddenly as by snubbing.

Again, it is possible to do much to limit the yawing of the airship by giving it suitable aerodynamic characteristics.

Having discussed the general problem of mooring, and endeavoured to show the reasons for the series of operations which are carried out in what is known as the Air Ministry System of Mast Mooring, it may be of interest to describe the masts which are at present being erected at Bedford and in Egypt, and are designed to fulfil these requirements.

Description of New Mooring Mast at Present Under Construction

The mooring masts that are in course of erection at R.A.W., Cardington, and the Airship Mooring Mast Base at Ismailia, Egypt, consist of a steel girder structure arranged in the form of an octagon. The base is 70ft. across and tapers towards the top to 25ft.

The structure is cross-braced and is made up of six sections of about 28ft. 6in. each and designed to take a pull of 30 tons in any direction at the top. At the top of the actual structure at a height of 170ft. is the passenger platform and the turret or housing which takes the receiving arm. This arm is mounted in gimbals so as to allow a free movement up to 30 degrees from the vertical. It is 24ft. long in the extended position and 16ft. when compressed, which allows a recoil travel of about 8ft. The recoil mechanism consists of a series of weights and springs, and allows for a recoil force of about one ton. This arm is in the extended free position during the mooring operation, but as soon as the ship's cone is locked in the cone at the end of the arm, this arm is then righted by means of a small motor and a train of gears. It is locked in the vertical position by racking in the inner sleeve by means of a small electric motor carried on the swinging or receiving arm. This motor is also used for extending the arm when preparing the mast for landing operations. The balance of this arm is such that it tends to return to the vertical with a small righting couple.

It should be observed that, contrary to a popular opinion, the masthead does not revolve, but only the receiving cone on the end of the arm; free motion is allowed the ship in other directions by means of a universal fitting on the nose of the airship.

These two cones are locked by means of three locking pins, which lock automatically but have to be released before the ship can leave the mast.

About 30ft. below the passenger platform there is a similar platform for searchlights and the signalling apparatus.

Up the centre of the mast runs the lift shaft, and also a staircase. The hydrogen and water and fuel mains, lighting and distant control cables for the winches, are led up the main legs of the structure to a convenient point at the top.

The hauling-in machinery is situated at the foot of the mast and consists of three steam winches fed from two tubular oil-fired boilers. These winches are designed to allow for a pull of 15 tons at a speed of 50ft. per minute, although the normal working load will be between five and ten tons. A clutch and hand brake is fitted and a distant control gear has been designed and erected on the landing platform at the top of the mast to enable all operations to be under the immediate supervision of the landing officer. Duplicate controls are fitted below in case of any breakdown to the distant control gear, in which case orders would be issued by telephone from the top of the mast.

The drum of each winch will carry about 4,000ft. of wire, 25-ton breaking strain.

Two pumps, each capable of lifting 5,000 gallons per hour against a pressure equivalent to 250ft. head, one steam-driven and one electric, are installed to provide ballast water when the airship is moored.

Fuel is also pumped up to the ship by means of a pump capable of lifting 2,000 gallons per hour against a pressure equivalent to a head of 400ft. The fuel oil will be stored in a large underground tank of 10,000 gallons capacity.

All this machinery is housed in one building near the base; living accommodation for a watch of the airship crew will also be provided.

To the man in the street the mechanism I have just described may appear complicated. I would like to point out, however, that the operation it is asked to perform is complicated.

It is reasonable to expect the mooring mast to follow the course taken by practically all new mechanical devices.

They start as a simple idea, become complicated as experience shows the necessity for additional refinements, and then by a process of combining and readjustment of detail, they are once more simplified, still retaining their efficiency.

The mooring mast has now reached the stage where necessary refinements have made it look complicated. There is no doubt that future designs will show many simplifications in detail.

Appendix I.

History of Mast Mooring

It is difficult to find out when mast mooring was first suggested, but it was believed that the first patents were taken out by an Italian; these have been allowed to lapse.

The first attempt to moor an airship to a mast in this country was made in 1911, when the Naval Airship No. 1 was moored some time at Cavendish Dock, Barrow-in-Furness.

In this mooring a short mast was used to which the nose of the airship was attached at a single point; the cars of the airship were made watertight and floated on the surface of the water. In this experiment the general behaviour of the airship at the mast was good, but owing to the Naval Airship being destroyed while handling out of her shed, they were inconclusive.

These experiments were carried out under the direction of Admiral Murray Sueter, M.P., at that time in command of the Naval Airship Section.

The next attempt was made by the Army in 1912. A mast was erected at Laffans Plain, South Farnborough, for mooring small non-rigids. This was the first attempt made at mooring in which the airship was moored clear of the ground or water.

The mooring gear was of the horizontal approach type, consisting of a large cone into which the nose of the ship was hauled.

The ship was never landed at the mast from flight, but was walked to the foot of the mast by a landing party and the nose of the ship hauled in.

The Beta rode out heavy rain and a wind of 37 m.p.h. on this mast.

The chief trouble experienced was the racking motion on the nose of the airship when riding, that rapidly caused the fabric to deteriorate.

No further experiments appear to have been tried after this, and at the beginning of the war mast mooring was still an unsolved problem, and in order to deal with the rapid airship development, sheds were erected all over the country, all forms of mooring being neglected until 1917, when experiments in connection with mooring of small non-rigids were carried out at Barrow, and experiments with rigid airships on a three-wire mooring system started at Howden and lately transferred to Pulham.

The first real attempt to moor a rigid airship to a mast was made at Pulham in 1919, a mast being erected and the bow of the R.24 specially stiffened for the experiment.

The principal part of the experiment was to test out the possibility of maintaining a large rigid airship at a mooring mast in all types of weather.

The airship was secured to the mast by means of a ball fitting on the airship secured into a cup fitting on the mast.

The head of the mast was constructed so as to be capable of rotating about a vertical axis, the ball in the cup gave a limited motion in the other two directions *i.e.*, pitch and roll, so that the airship had free motion about a fixed point on the top of the mast.

In the first case the airship was walked to the mast by means of a landing party, and remained on the mast for three weeks, riding out winds of up to 35 m.p.h. and gusts up to 43 m.p.h. with heavy rain.

These experiments proved that an airship could be maintained at a mooring mast in fairly bad weather, and were sufficiently convincing to forecast that a properly designed airship should be capable of riding at a mooring mast in any winds likely to be met with under normal conditions.

Up to this time all experiments had been carried out with a view to proving the possibility of riding to a mooring mast, the airship being handled on the ground by a landing party, and walked up to and attached to the mast with the landing party; no attempt had so far been made to land an airship directly on to the mast, but on completion of the above, the second part of the experiments, *i.e.*, the landing to a mast, were started.

Experiments were carried out on five days.

November 4th.—The R.24 was taken out of the shed in a wind of about 5 m.p.h., walked out to the mast, the mooring rope attached, the ship ballasted up, and hauled to her correct position at the top of the mast by a kite balloon winch.

The method of landing was what is commonly called the horizontal approach, that is, an endeavour was made to keep the airship in trim just light and with the engines running astern.

In this light wind little trouble was experienced, except that the water in the radiators boiled.

November 7th.—Flying trials carried out, wind 5 m.p.h.

The ship was brought out on to the landing ground, ballasted up, flown to the mast, the trail rope dropped and the ship hauled up and secured to the mast, only six men being used in landing the ship.

No mention is made in reports available about any surging on the trial, but from other sources it is ascertained that a certain amount of surging did take place, in spite of the light wind, causing the masthead to swing round, and the ball on the nose of the ship to swing over the coupling.

This is borne out by the recommendations in Captain Thomas's report that a steel plate should be provided over upper half of coupling, of diameter about 10ft., and that a rack and pinion should be provided to enable masthead to be rotated and locked into position.

December 9th.—R.24 taken out of shed in a wind of about 5 m.p.h.

Handled to the foot of the mast, ballasted up, and hauled up into position.

Easing-off experiments were then carried out, the ship being eased off about 60ft. and again hauled back and secured several times.

December 10th and 12th.—Further easing-off trials carried out.

The landing on the 9th the airship was landed light and came into the mast at about 45 degrees; this caused trouble with the type of masthead, which was designed for horizontal approach.

The easing-off trials on the 10th and 12th were in winds between 10 and 28 m.p.h.

The reports on both days show that when on a short wire the surging was very considerable, even with the engines going astern, at times the wire making an angle of 90 degrees with the ship.

The above trials finished the experiments with R.24.

These experiments had shown the value of a mooring mast, and proved that an airship could ride safely at a mast in bad weather, but also showed that considerable modifications in the method of landing would have to be introduced before landing to a mooring mast was safe and reliable.

As the commercial value of the airship was now receiving consideration, and it was realised that the airship could not be a commercial proposition as long as it was necessary to provide a landing party of 200 to 300 men, it was decided to carry out further experiments to overcome the difficulties experienced in landing to a mast with R.24.

A series of experiments were therefore started under the Director-General of Civil Aviation, the R.33 being used for these experiments.

Two main faults appeared to stand out in the previous method of landing :—

(1) The necessity of keeping the airship in equilibrium while the landing was taking place; this was in the opinion of all airship pilots extremely difficult and dangerous.

(2) The violent surging when airship was nearing the mast on a single wire and the necessity of finding some method of checking this surge.

In order to overcome these two difficulties, the Air Ministry so-called vertical system of mooring with side guys was introduced.

Although the vertical system of landing appeared to have everything in its favour, both from a safety and ease of handling point of view, it was recognised that the necessity for laying out side guys several hundred feet from the mast was a drawback.

Before actually employing these side guys, therefore, another attempt was made to land the airship on a single wire; the surging noticed in R.24 was still more violent in R.33, and the nose of the airship was damaged on the masthead.

It was therefore decided that side guys, or their equivalent, were essential, and since their introduction no airship has been damaged in landing once the tension was taken on these side guys.

The original radius of the side guys was 300ft. from the foot of the mast, but as it was realised that the sooner the side guys could be brought into operation the safer the landing, this radius was increased to 500ft., and for the future masts it has been again increased to 750ft.

Appendix II.

The diagram shows the moment about the bow of R.33 at various angles of yaw in a steady wind. It will be seen that the moment is a small disturbing one for angles of yaw 0 degrees and $4\frac{1}{4}$ degrees, but becomes a restoring moment for greater angles. Consequently, in a steady wind, this ship will lie at an angle of $4\frac{1}{4}$ degrees to the wind direction. The position of the ship with its long axis parallel to the wind is one of unstable equilibrium.

Appendix III.

A Method of Calculating for an Airship moored to a Mast, the Degree of Instability Due to a Temperature Gradient and the External Weight Necessary to Counteract It.

Let T be the temperature at the height of the mooring point, measured in °F. on the absolute scale.
,, G be the temperature gradient, *i.e.*, let the temperature fall G °F. per foot rise in height.
,, C be the gas content of the ship in cubic feet.
,, K be the lift in lbs. per cu. foot of gas at $T°$ F. abs.
,, L be the length of the ship.
,, L_1 be the distance measured along the ship's centre line of the CB and the CG of the ship.
,, d be the perp. distance of the CG below the centre line in feet.
,, f be the perp. distance of the CB above the centre line in feet.
,, θ be the angle of inclination of the ship to the horizontal, positive as drawn in Fig. 1.

If an airship is in trim when moored to a mast in still air, a small displacement in the vertical plane gives rise to moments due to the weight, the lift, and the temperature gradient existing at the time. In addition, if a certain inclination is exceeded, a righting moment is provided by the ship lifting, or tending to lift, weights off the ground.

The moments about the mooring point due to the weight and the lift are respectively

$$KC\,(L_1 \cos\theta + d \sin\theta)$$
$$-KC\,(L_1 \cos\theta - f \sin\theta)$$

giving a nett clockwise moment of

$$KC\,(d \sin\theta + f \sin\theta)$$
$$= KC\,(d+f) \sin\theta.$$

Let A be the cross sectional area of the gas contained in the ship, at any section distant l from the mooring point. Considering the elementary volume $A\delta l$, suppose its centre of volume to be g feet above the centre line. Then the

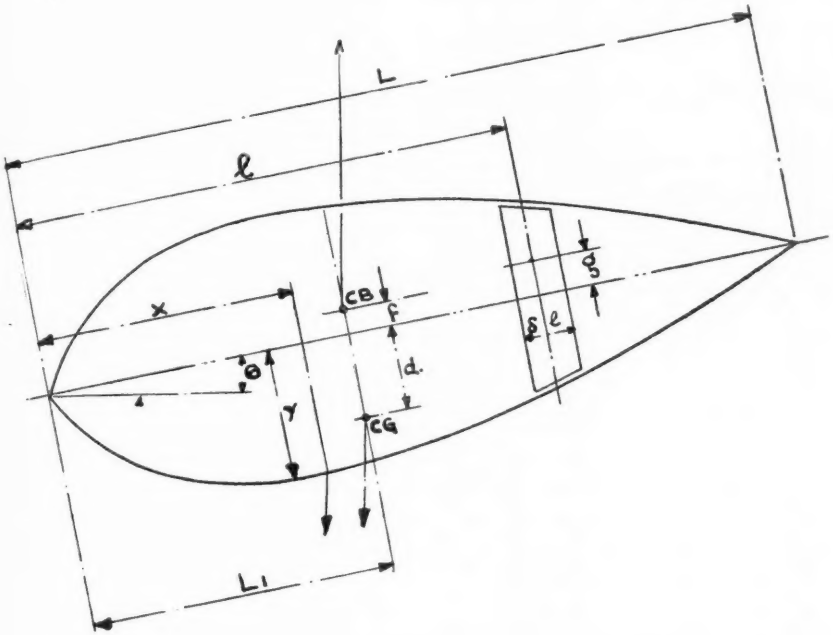
moment due to the effect of the temperature gradient on this elementary volume is

$$= -\rho A\delta l\ G\ (l\sin\theta + g\cos\theta)\ (l\cos\theta - g\sin\theta)/T$$
$$= -\rho A\delta l\ (G/T)\ \{\ \tfrac{1}{2}\ (l^2 - g^2)\sin 2\theta + gl\cos 2\theta\ \}$$

where ρ is the density of air in lbs./cu. ft.

The total moment due to the temperature gradient is

$$-(\rho G\sin 2\theta)/2T\int_0^L Al^2dl + (\rho G\sin 2\theta)/2T\int_0^L Ag^2dl - (\rho G\cos 2\theta)/T\int_0^L Agl\ .\ dl$$



Then, if m is the righting moment provided by external weights, and if

$$M = \int_0^L Al^2dl$$
$$N = \int_0^L Ag^2dl$$
$$Q = \int_0^L Agl\ dl$$

For equilibrium

$$-(\rho G/T)\ (\tfrac{1}{2}M\sin 2\theta) + (\rho G/T)\ (\tfrac{1}{2}N\sin 2\theta) - (\rho G/T)\ (Q\cos 2\theta)$$
$$+ KC\ (d+f)\sin\theta + m = 0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For the case of the ship full of gas, the CB is probably very close to the centre line; we may reasonably take f and g as zero, which deletes N and Q from (1), reducing it to

$$-(\rho G/T)\sin\theta\cos\theta M + KCd\sin\theta + m = 0$$

or

$$G = KTCd/\rho M\cos\theta + mT/\rho M\sin\theta\cos\theta \quad . \quad . \quad . \quad (2)$$

For small displacements, before the ship begins to lift the ground weights,

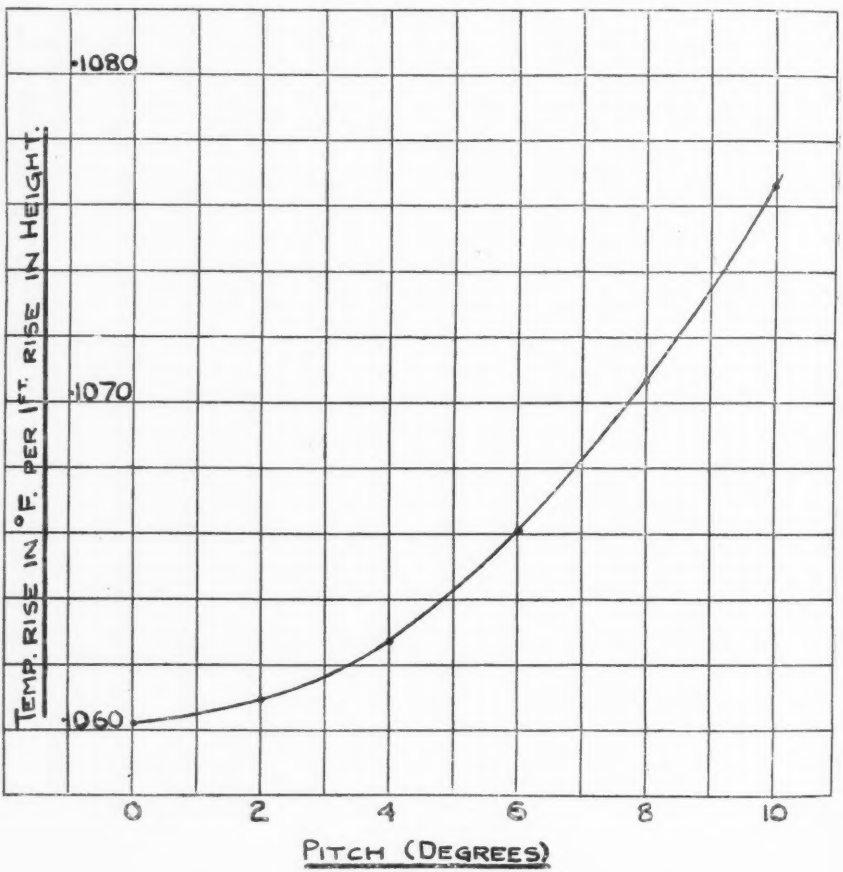
$$G = KTCd/\rho M \cos\theta \quad . \quad . \quad . \quad . \quad . \quad (3)$$

or, putting $M = Ck^2$

$$G = KTd/\rho k^2 \cos\theta$$

k is the radius of gyration of the lift about the mooring point.

In practice, the angle θ is kept within desirable limits by attaching points on the ship to pairs of heavy wheels initially resting on the ground, which supply a righting moment when the pitch tends to become too great. If elastics or springs are contained in the attachment, this moment comes on gradually.



Suppose, for any one pair of wheels having springs included in this way, the ship can pitch α° to the horizontal before loading the attachment, which then extends one foot for every p lbs. increase of load. If the point of attachment on the ship is Y feet perp. below a centre line point distant X feet from the mooring point, then for an angle $\theta > \alpha$ the righting moment due to the pair is

$$p\{X(\sin\theta - \sin\alpha) - Y(\cos\theta - \cos\alpha)\}\{X\cos\theta + Y\sin\theta\} = U_1 \text{ say} \quad (4)$$

If these wheels leave the ground when $\theta=\gamma$ and their weight is W

$$W=p\{X(\sin\gamma-\sin\alpha)-Y(\cos\gamma-\cos\alpha)\} \quad . \quad . \quad . \quad (5)$$

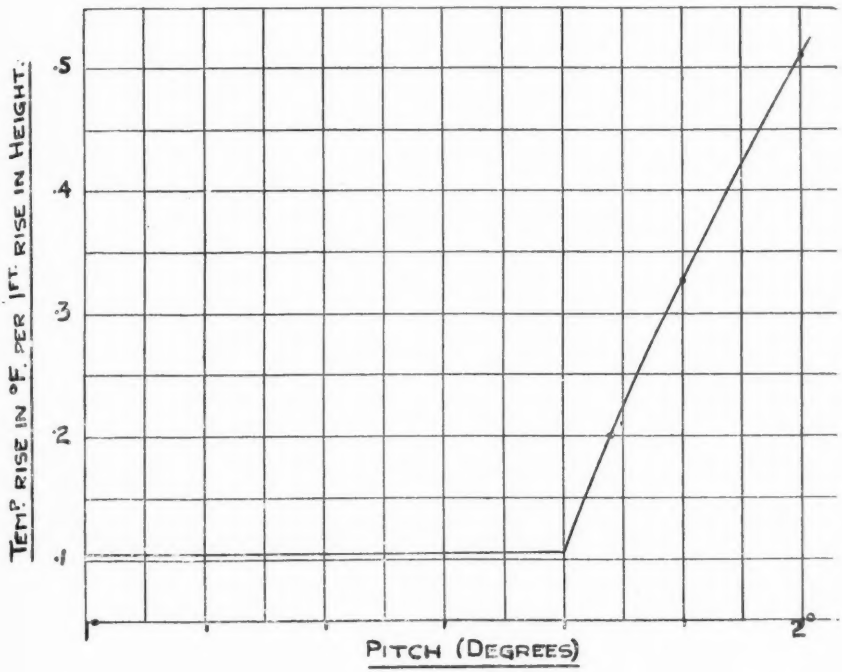
and the moment is

$$W(X\cos\theta+Y\sin\theta)=U_2 \text{ say} \quad . \quad . \quad . \quad . \quad (6)$$

When more than one pair of wheels is used (two pairs is usual), the total righting moment m is given by

$m=\Sigma U_1$ for all wheels still in contact with ground.

$m=\Sigma U_2$ for all wheels off the ground.



When $\theta=0$ the smallest temperature gradient which can cause an unstable tendency is (from equation (3)) given by

$$G=KTCd/\rho M \text{ for the case of a full ship.}$$

The effect of any gradient less rapid is immediately smothered by the existing static righting moment.

Considering first the simple case when no ground weights are operating, we have for R.33

$$C=1.958\times10^6 \text{ ft.}^3$$
$$d=23 \text{ ft.}$$
$$M=2.0343\times10^{11} \text{ ft.}^5$$

Then, taking

$$K=.07 \text{ lbs./ft.}^3$$
$$\rho=.076 \text{ lbs./ft.}^3$$
$$T=520°\text{F. abs.}$$

G from (3) can be easily calculated. It has been done for a range of 0° to 10° pitch and the resulting curve is shown in Fig. 1.* It is seen from this curve that while for $G < .10602$ the ship is still stable, yet for G only slightly greater than .10602 large values of θ are possible when no ground weights are used.

It is now proposed to consider the effect of the wheels used to provide the moment m in the case of R.33.

Two pairs are used, each weighing 808 lbs.

One pair is attached at frame 21, so that $X_1 = 319.4'$ $Y_1 = 39.29'$; the other at frame 33, so that $X_2 = 516.25'$ $Y_2 = 26.735'$.

The spring for each pair extends 3′ in taking up the full weight of the wheels, so

$$p = 808/3$$

The arrangement aimed at is for the rearmost pair to be on the point of leaving the ground, and the foremost pair to be on the point of extending its spring when the ship is up 2° by the stern.

Thus for the foremost pair $\alpha_1 = 2°$.

For the rearmost $\sin \alpha_2 = (X_2 \sin 2° - 3')/X_2 = .029085$.

$$\therefore \alpha_2 = 1° 40'$$

Also for the foremost pair

$$\sin \gamma_1 = X_1 \sin 2° 3'/X_1 = .0443$$

$$\therefore \gamma_1 = 2° 32'$$

For the rearmost pair $\gamma_2 = 2°$.

Using these values in finding the appropriate m from equation (4) or (6), and substituting in equation (2), the curve of Fig. 2 results. Even the most extreme temperature conditions do not bring the foremost wheels into operation, and it is seen from the curve that the rear pair have a rapid stabilising effect, as the range exhibited is only 1° for a change in temperature gradient of .4° F/ft. To take an example, for a pitch of 1° 50′, the temperature gradient, for equilibrium *without* wheels (Fig. 1) is .10607 and *with* wheels (Fig. 2) it is .32562.

Discussion

Mr. Brewer, before opening the discussion, said: I am sure we have all heard a very interesting paper, and I hope it will be well discussed. There are several problems in mooring airships which have been raised and they should now be thoroughly threshed out.

Group Captain P. F. M. Fellowes: First of all I would like to be allowed to offer Major Scott my warm congratulations on the very interesting paper he has just read. I expect that everyone here knows that Major Scott himself played a very large part in the evolution of the Air Ministry mooring system. I feel myself it was very fortunate that the individual in charge of the development was a trained engineer and also an experienced airship pilot. I think it is mainly to this latter quality in him that we can attribute the success which has been achieved. It is interesting to know that the Americans have had this system in use for some years and so far as we know have made no improvements in it except, perhaps, in matters of detail.

However, even in the existing system, as we have been told, there are certain improvements which can be made. I found it extraordinarily difficult to visualise the problems in mast mooring before I had actually seen the process in

* For negative values of θ the resulting curve is symmetrical about the vertical axis with the curve given.

action and possibly you may be in the same quandary. Therefore it may be interesting as an instance of how important these improvements are to tell you that it is possible to feel with the present system, when standing a long way aft, a sensation as if the walking way of the keel were being twitched from under one's feet when being hauled into the mast, if one of the side guys is allowed to slacken and then snub. The fact that this sensation can be felt gives you an idea of the stresses which can be set up on the ship if riding on a short stay on a single wire. It will also be realised it is very important to have the most sensitive and controllable winch engine available and also a very well trained mast crew, in order to prevent unnecessary jerks on the nose of the ship.

I should like to take this opportunity of removing an impression which was made in many people's minds in 1921 when a party of Members of Parliament, who were taken for a trip in the airship R.36, had to stay up for longer than had been intended; meteorological conditions for landing became bad while the ship was up, due to the formation of a heavy temperature gradient and it was considered unnecessarily risky to bring her down until this gradient had lessened. The point I wish to make clear is that an airship of the size of R.36 is no more fitted for short flights than is a liner for ferry duties across the Mersey, and I hope that all who are interested in airships will in future regard large airships more in the light of those mediums of travel such as liners, battleships, or large land convoys which require considerable organisation and preparation before they either commence or terminate their voyages or journeys.

In the future captains of airships will no doubt select a time of arrival at their destination which will give them either an inversion or no gradient at all, and even if contrary winds prevent them doing this, after a voyage of two, three or four days, passengers will not consider it a very irksome matter to wait an hour or two in order to ensure a landing without any risk of damage to their temporary home. This will be equivalent to a steamship missing the tide owing to adverse weather conditions and being obliged to await a suitable opportunity for entering the harbour.

A further point I would like to touch on is the floating base for mooring airships. At first sight this appears to be a wonderfully attractive proposal as the floating base is necessarily a mobile base and it appears to afford the advantages of trying out various routes economically. However, I have reason to doubt whether this really is so from an economic point of view, and from the structural side, when the immense height and rigidity of a modern mooring mast is appreciated, it seems doubtful if any but the largest ship could safely navigate the seas with the masts in place. As far as we know the Americans have only used the mooring mast on the Patoka in good weather and when the ship was lying in a sheltered roadstead. They have not used her for some time and it may be that they have come in contact with the difficulty of the height of the mast in regard to the funnel, super-structure, etc.

A point which possibly has not been generally realised is that with a mobile floating mooring mast, the risk of the airship swinging over the funnel and mast structure cannot be disregarded. This means that the mooring mast must be sufficiently high above the funnel structure to ensure the airship swinging clear whatever may be her orientation with regard to the ship, and as the mooring mast we are erecting on a perfectly flat piece of land is 200 feet high, it would be difficult to argue that a mooring mast erected on a ship may be of a lesser height. In fact, I believe that when it becomes possible to test the expense and possibility of the two methods, the land mooring mast, or possibly a mooring mast built on a rock and surrounded by water will always prove more efficient from all points of view than a mobile floating mooring mast, but at the same time I do not say it is impossible to mount a mast on a ship nor that it should not be tried, but I do feel that it should be approached with the greatest caution.

Finally I would like to say that in my opinion recent events have given the public an exaggerated idea of the dangers which an airship will have to encounter when flying in the air. I personally believe that an airship will be able to contend with any weather conditions she may have to meet, provided the necessary precautions are taken and weather warnings supplied. As regards the special case of an airship lying at the mast, I think there is no doubt that the possible effects of weather demand the closest investigation, but if very bad weather sets in and her instruments warn her she must go, I am convinced she could ride out any weather in the air, if properly handled.

Lieut.-Colonel V. C. RICHMOND: There are two points I should like to emphasise. One is that we have been working in the past with imperfect tools, and therefore hasty judgment should not be formed on the results obtained from these imperfect tools.

With regard to the ship itself, no airship, so far as I am aware, has been particularly designed with mast mooring in view. As Major Scott said, it is possible to provide an airship with aerodynamical characteristics which will greatly reduce the difficulties of mooring without harming the usefulness of the ship for normal flying operations.

The other point is in regard to the ship's strength. One has heard a good deal of misinformed criticism of the mooring of airships, this criticism often taking the form of stating that an airship can never be made strong enough to be moored safely to a mast. It is a truism that you can make anything strong enough for anything if, first, you know how strong you want it and, secondly, you are able to put enough material into the job. I think Major Scott has shown to-night that we have gone a long way towards knowing how strong an airship needs to be, and the only thing I can add to his remarks is this: That so far as one can see from the pessimistic calculations available, there is no reason why you cannot make the nose of the airship amply strong for the job without excessive weight. In fact there is no need for the longitudinals of the ship to be as strong at the nose as they are in the main body of the ship. I am satisfied there is no engineering technical difficulty in making the nose of the ship strong enough to hold the ship at the mast in unsteady weather of the type he has described with the degree of unsteadiness such as is shown by our present meteorological information.

With regard to the new mast, I need say nothing about the strength of that. I feel sure you will all have been convinced by the pictures you have seen that this is a very different proposition from our little mast at Pulham, and that a good deal of thought has been put in to make it strong enough for the job for which it is required.

Mr. H. B. WYN EVANS: The importance of the subject of Major Scott's paper is of course very evident to all who are interested in airships, and we have to thank him for putting the problems involved so ably before us.

I think one ought to say right away that it is mast mooring that renders commercial airships a practical proposition. We have to legislate for airships living at the mast without a shed to run into when bad weather comes along. The mast in Egypt has no shed, and I believe that four or five of the masts in the United States have no sheds either. That only tends to emphasise the enormous importance there is in research and investigation of the problems connected with mast mooring. As Colonel Richmond has said, I do not think we need be afraid of making the ships strong enough, provided that we know all the forces with which we have to contend, and I am afraid that at the present moment we are rather apt to underestimate the effects of gusts, the changes of direction of the wind and probably, though not so much, the variations in temperature. I have always understood that changes in the direction of the wind can take place in extremely short periods of time, and I have recently asked

one or two questions about this. Actually, among the records that were taken when the Shenandoah broke away it was shown that a change of direction of the wind of 45° took place in less than one second. Another interesting point I ascertained, and here I am open to correction, was that it was a gust that first carried away the top fin of the Shenandoah before she broke away from the mast.

A further point was that when the Los Angeles was moored to the Patoka in the West Indies, some change in the direction of the air or sudden temperature effect actually put her tail down into the water before she could be controlled. Therefore it is to the meteorological experts we must look for the data which is so necessary for ensuring that the ship is strong enough to meet all the forces with which she has to contend when moored to a mast.

Wing Commander T. R. CAVE-BROWNE-CAVE: Mr. Wyn Evans referred to mast mooring as being the essential factor for commercial airship work. I submit that it is equally essential in military airship work. The naval operations which led up to the battle of Jutland were actually held up by the German Commander-in-Chief because the airships which he considered essential to give him the disposition of the English forces were weather-bound in their sheds. He finally was forced to proceed with only part of his airship force. It would be very interesting to know what would have happened if he had had airships available before the operations started, to give him our dispositions sufficiently accurately to allow him to isolate our battle cruiser force.

Major Scott refers to the employment of a mooring mast on a monitor or other ship. In 1921 figures were worked out when it was proposed to put a 150ft. mooring mast on a monitor. The calculation which surprised me most was the extreme stiffness of the monitor. The monitor considered was of 6,000 tons, with a metacentric height of 10.5 feet. A 10-ton pull at the masthead produces a roll of only 1.5 degrees. Imagine the monitor anchored and rolling with the small roll of 5 per cent. The stiffness of the monitor is such that to stop this roll an enormous force at the masthead would be necessary. The period for a swing of 5° on this monitor was only five seconds, out to out on the same side. and the head of her 150ft. mast would travel 13 feet on each side of its mean position. To constrain an airship of 150 tons to that motion would involve a force of 100 tons at the bow. To prevent the monitor from rolling even slightly it would be necessary to beach her except in almost totally enclosed water.

The Author did not refer to the necessity of the airship engines being able to go astern. This involves some extra machinery complication which one would like to avoid. It would therefore be interesting if Major Scott would explain whether it is necessary to go astern only to check the forward way of the airship or also to exert a sternward force which will tend to pull the airship into line with the mooring wire.

Major C. C. TURNER: One question about stern thrust. Is it possible to use swivelling propellers to give an airship greater command when approaching the mast, and greater command over its behaviour at the mast? It would be interesting to know whether swivelling propellers will be used in the R.101.

One other point, the effect of climate or temperature on the airship at the mast. I believe we have no data relating to mooring airships in tropical countries, or where there is very high temperature. I wonder whether the effect of very hot sun on an airship at the mast when there is no way on to create a draught might not be underestimated.

Mr. W. A. D. FORBES: May I first say how much I appreciate the opportunity of listening to this paper by so eminent an authority as Major Scott.

There are one or two points in which I am particularly interested. The first is that the paper brings out how poor our knowledge is of the structure of

the natural wind. I have come across this matter in connection with the landing of aeroplanes on the decks of aircraft carriers. A steam jet is commonly employed to indicate the direction of the wind, and occasionally comparisons have been obtained between such a jet and an electric yaw meter which indicates and records the instantaneous direction of the wind at a particular spot. It is found that the natural wind is never steady, and even when the steam jet is apparently steady, or reasonably so, an examination of the yaw meter readings shows that the mean direction of the wind oscillates with an amplitude of say 10° or 15°, and that superimposed are very rapid fluctuations of 20° or 30°. The figure of 45° change in direction in a second, mentioned by Mr. Wyn Evans, could readily occur. Of course, taken over a large area or volume these fluctuations would probably cancel out and the effect on an airship might not be large, but it does show the need for a large number of continuous and not instantaneous synchronised readings in order to determine exactly what is happening.

Major Scott refers to two cases in which variations in direction or velocity would cause a lateral force of 4.5 tons. There is a further cause which may possibly account for such a lateral force, namely, the existence of a velocity gradient. The effect of such a gradient is not mentioned in the paper, although it has possibly not been overlooked. The existence of a velocity gradient is sometimes advanced to account for the fact that the air disturbances over the deck of a ship are not so serious as wind channel experiments on models would suggest. Data concerning wind gradients is somewhat scarce, but it appears that at 50 feet above sea-level the velocity is on the average only about 85 per cent. of that at 100 feet.

The photographs of the masthead are most interesting, and it is quite evident that in the new mast at Cardington the weight of the mast head is some 20 or 30 times as great as the Pulham mast head. This is an important matter from the point of view of a mobile mooring mast. I can confirm what Wing Commander Cave has said in regard to the stiffness of a monitor, in fact it is really stiffer than he stated, as the metacentric height might easily be in the neighbourhood of 30 feet or even greater. So far as stability is concerned the large weight of the masthead would not preclude its use in a monitor, even though its total weight were of the order of 50 or 60 tons, as the figure of 26 tons for the weight of the moving arm, given by Group Captain Fellowes, would imply. There would be no need to worry about stability, and in sheltered waters a monitor would be as steady as a rock and there should be no difficulty in mooring an airship so far as motion of the masthead is concerned, while, if necessary, the monitor could be beached and remain so while at a particular port.

There is, however, one aspect of the question that is disturbing. It must be remembered that although one would not dream of mooring an airship to a monitor in a seaway with the vessel rolling, the monitor itself would be called upon to steam from port to port, and would have to be seaworthy under all conditions. A vessel of this character would behave exactly like a raft and would take up the same slope as that of the waves. If broadside on to waves having a length of three or four times the beam of the ship—such deep sea waves have slopes of 10° and a period of about $5\frac{1}{2}$ seconds (this is also roughly the still water rolling period of a monitor)—the linear acceleration at the top of mast, acting at right angles to the mast, would be greater than gravity, possibly 1.2g. In these circumstances the bending moment about the base of the mast due to the inertia of the masthead would be that due to a normal pull of about 70 tons, or more than twice the horizontal pull the Cardington mast is designed to stand. No doubt the horizontal pull of 30 tons for the Cardington mast is largely in excess of what is likely to be experienced, whereas the force due to the rolling of the monitor would be that actually felt when rolling to the extent indicated.

Major Low: His own energies were directed towards aeroplane problems and that he was not sufficiently informed to make any remarks on airship design, save of a general nature. But he was much impressed by the systematic investigation in the paper of some of the details of the airship problem. If the same care and labour were being bestowed on all the difficulties that arose it gave him, personally, a renewed degree of confidence in the possibility of final success.

Wing Commander Cave had referred to the strategic effects on the naval situation at Jutland of the absence of airships, which he attributed to the want of mooring masts.

The official German history stated that preparations were begun on the 8th May for a sortie of the main German naval forces on the 17th, but a series of troubles with boilers, condensers, etc., and the usual inevitable dockyard delays in repairing them, postponed the operations time after time.

Finally, the scouting submarines which had gone out on the original time-table had to return to harbour about the time the battle fleet was ready to sail—the morning of the 31st—without any effective information. Airship reconnaissances suffered from disabilities of another kind. The speaker agreed with Wing Commander Cave that some of the naval airships were wind-bound in sheds of the fixed type, but others were available, in particular those which were housed in rotating sheds. Had mooring masts been thought of and erected, no doubt the whole airship force would have been available on the day, but those that actually went out saw neither fleet in the thick weather and gave no information before the battle.

Our own solitary seaplane observer reported maximum visibility four miles and stated that on no occasion did he see both fleets at the same time. Thus both forms of aircraft were rendered almost ineffective by fog.

It might be asked why the German fleet risked coming out in thick weather, and did not wait at least a few days longer on the chance of clearer weather.

It was common knowledge that the German battleships carried large crews in cramped quarters, accommodation having been sacrificed to extreme sub-divison and heavy protection and armament. It was thus not possible to keep the crews indefinitely on board without serious loss of efficiency in the human element, and in the absence of positive information this may have been the determining factor in the decision to come out with the whole fleet, when at last ready, rather than disperse it, part to the Baltic, the crews of the remainder to their shore barracks and begin all over again later.

If that were so it was a striking example of the inevitable workings of the compromise forced on all designers, that the Germans had purchased at a price which brought them in this curiously indirect way into conflict with overwhelming superiority of numbers, the qualities which made their individual ships so formidable in actual battle.

Airships involved compromises like battleships, or aeroplanes, or any other engineering structures and he hoped, as everyone concerned with aeroplanes would hope, that their colleagues concerned with airships would have the good fortune, deserved by such work and foresight as were exhibited in the paper, to obtain the best compromise between the conflicting requirements demanded of them.

Mr. BREWER, before calling on Major Scott to reply to the discussion, said: I was very much interested to hear how the kite balloon had been of assistance in some of the problems which arise in the stability of airships, especially so with regard to the length of rope that is used to bring the airship up to the mooring mast. With kite balloons we always found that the greater distance from the ground the steadier the balloon rode in the wind, for the very obvious reason that

the kite balloon has a distance of yaw, and held by a long enough rope it takes a longer time for the kite balloon to arrive at the end of the yaw where it reverses its attitude and returns in the opposite direction.

I do not know whether this question of yawing has ever been properly investigated, but I have always imagined that it was set up by the difference between the weight of the tail and the weight of the bow and for that reason I was rather surprised to learn that kite balloons had been of much service in problems of the stability of airships. I have always likened a kite balloon to a boat being towed from a bank, whereas with an airship where you have no surplus lift you can only tow that airship, or moor it, by attaching to the actual bow. The difference between the problem of kite balloon mooring and airship mooring seems to be in the fact that the kite balloon has a large margin of surplus lift while an airship has none.

I was surprised also to learn the tremendous effect which change of temperature has on the stability of an airship moored to a mast to set up oscillations in a vertical direction. I should not have thought that change of temperature would have been nearly quick enough to affect this.

Major SCOTT, in his reply to the discussion, said: I expected to get a lot of criticism, but actually there has been very little.

Two speakers raised the point of wind variation, in one case a variation of 45 degrees in one second was quoted and in the other case very rapid changes. I have seen weather charts which have apparently indicated changes of this sort. When we had R.33 on the mooring mast at Pulham, changes of this degree were shown on the chart and yet we have definite evidence that the load on the bow was never over 4.52 lbs. It means that these rapid changes of angle in a very short space of time must be of comparatively small area at any rate in this country and do not affect the airship except over a comparatively small area, and therefore do not produce heavy loads on the bow of the airship. In considering the load exerted on the bow of the airship on the mast we have always assumed that the wind was acting at the same angle for the full length of the ship, which means a direction variation over a big area. The fact that big changes are shown on an anemometer need not frighten the designer, although, as I said in the paper, more information is required on this subject. It is for this reason the Meteorological Department are erecting four synchronised anemometers at Bedford for tests on the structure of a gust.

Another point raised by Mr. Wyn Evans was in regard to the Z.R.3 putting her tail in the water. This was probably due to temperature alteration. Wind changes would not tend to have this effect, but it could quite easily be done if the ship is riding to the mast and no wheels or the equivalent are fitted. R.33 in a temperature gradient of 10°F. per 100ft. would be quite steady, whereas in a gradient of 11°F. per 100ft. if no weights were employed she would put her tail in the water. If weights are employed, they need not be heavy; it is possible to weather gradients up to 50°F. per 100ft. without danger of the tail entering the water. This is a difficulty which has now been overcome.

Wing Commander Cave-Browne-Cave asked the question, was astern gear needed for airships? In all airships it has been specified that a certain percentage of engines shall be capable of going astern. The reason for this is to afford a means of checking the way of the airship when coming up to the mast or a landing party. When you are landing to a mast and you wish to drop the main hauling rope to the men on the ground, you want the airship practically steady as far as horizontal direction is concerned, though it may be rising slowly. It is very difficult to do this without astern gear. The engines going astern when the airship is on the main wire do not appreciably affect her steadiness. In the past there has been a difficulty with the radiators when going astern, boiling taking place within about ten minutes.

In reply to Major Turner, swivelling propellers were fitted to the R.9 and R.23 classes, but fitting them means sacrificing a good deal of useful lift and, owing to the gear drive, a considerable loss of efficiency; the advantage gained was so small that it was the general opinion that they were not worth fitting. We look upon swivelling propellers as an excellent thing in a small ship to teach people how to fly and pull them out of trouble, but in a ship where you are considering long distance journeys and where efficiency and reliability in transmission are of first importance, they are not justified. Rather than sacrifice this efficiency and reliability for an emergency which would probably never occur, that is an emergency where swivelling propellers would save the ship, it is far better to carry additional water ballast, which would have the same effect.

The question of superheating in a hot climate has been carefully considered. A paper written by Colonel Richmond and myself on this subject was published in the journal for March, 1924; in this we endeavoured to forecast the effect of superheating and the degree of superheating likely to be met with in hot climates. The data available was not very full, but the investigations we were able to make tended to show that the superheating would not be so serious as it was at first anticipated. The question of ventilation between the gasbag and the outer cover is a very important one and is being very carefully gone into.

With regard to the difference in the velocity gradients of wind at the top and bottom of the mast, large differences have been experienced. I have never noticed that it had any effect on the airship. However, it is a point that will be examined.

I should like to thank Major Low for his very kind remarks and for the information about the battle of Jutland. It is most interesting to get information of this sort. Airship people think in airship terms, and it is very hard for people who have nothing to do with them to realise the application of the airship. It is very interesting to hear that this question has been carefully considered and its relation with the battle gone into by people who are outside airships.

The Chairman referred to the use of kite balloons in the mast experiments. The kite balloons were used for the preliminary experiments at Pulham, not so much because we expected a kite balloon to behave like an airship, but more in connection with different types of mooring. We used a kite balloon on a single wire as a comparative test. There was one very interesting point that came out about a kite balloon on a single wire. We measured the actual distances the kite balloon yawed at various heights, and a distance from the masthead the yaw was practically constant and independent of height. This only applied when some distance from the mast. When near the mast the height played a big part in the yaw. The Chairman said he was surprised that variations in gas temperature could occur quickly enough to give trouble at a mast. I am afraid I did not make myself clear—gas temperature remains practically constant but the air temperature may vary rapidly. It is the difference between the two that causes the alteration in lift.

PROCEEDINGS

SIXTH MEETING, SECOND HALF, 61ST SESSION

At a meeting of the Royal Aeronautical Society, held in the lecture theatre of the Royal Society of Arts, at John Street, Adelphi, London, W.C., on Thursday, March 18th, Mr. Alan Cobham delivered an address on "Long Distance Flying," in the course of which he referred to his flight from London to Cape Town and back and some of the lessons to be learned therefrom. Colonel H. T. Tizard, F.R.S., presided.

The CHAIRMAN: It is a very great pleasure to welcome Mr. Alan Cobham here to-night. I think he must be getting tired of hearing his praises sung and, indeed, it is rather difficult to find words in which to express our appreciation of his long-continued and arduous services to British aviation, culminating in this recent magnificent flight by him and his colleagues to Capetown and back. I take this opportunity of extending our congratulations to the manufacturers of the machine and engine, and to all those concerned with the whole flight. I shall not be going too far in saying that it is a magnificent triumph for home produced personnel and material and an invigorating tonic for all pessimists as to the future of British industry.

LONG-DISTANCE FLYING

BY ALAN COBHAM.

There has been little or no time, since my return from Capetown, to work up a paper worthy of this occasion on the subject of long distance flights. This subject encompasses so much that I feel that the only way in which I can at all tackle it is to endeavour to classify the various branches of long distance flying work and deal with each particular aspect separately.

I suppose there are two main types of long distance flying, firstly, long non-stop flights, and secondly, long flying journeys where many landings are made. To commence with I will deal with long non-stop flights.

Long non-stop flights, up to the present, have mostly been run purely as stunts or demonstrations of propaganda of some particular type of aircraft. These flights are very spectacular, and I suppose will always be a good advertising medium. There have been a few occasions when such flights have been undertaken as a commercial proposition to carry some important dispatches, photographs or special passenger.

We have come to that stage in aviation when the length of a long non-stop flight depends practically on the petrol capacity of the aeroplane, which for the occasion no doubt has been increased until the weight of fuel on board has brought the machine up to its maximum loading. So therefore the length of a long distance non-stop flight depends upon the amount of load the machine can carry in the form of fuel, although it is up to the designer to work out which is most economical, namely, the machine that can lift a tremendous load at a moderate cruising speed, or the very fast machine which cannot carry such a big load. From my own experience the greatest long distance efficiency comes from a machine which is halfway between these two extremes.

Then, of course, comes the question of petrol economy, and here I can say that the extra speed gained by opening out the engine in no way pays in distance

covered for the extra fuel used in so doing, and the greatest distance on a given quantity of fuel can always be obtained by running at approximately two-thirds of one horse-power. The extra number of miles per hour that is gained by opening the engine well out in no ways pays for the enormous extra consumption of petrol.

There is one great disadvantage to a long non-stop flight, especially if it is adopted for a commercial purpose where it is imperative that the machine reaches its destination not only more or less on time, but reaches it for certain, as schedule. This disadvantage is that of the necessity of an enormous petrol reserve, far greater in proportion to a short distance flight, which must be carried in case of emergency in the form of a head wind. Supposing one wishes to fly 1,000 miles non-stop on some particular special errand, and one's cruising speed is 100 miles per hour. It would be necessary to have on board, shall we say eleven hours petrol to ensure the machine getting there, providing it is flown in still air. This will mean carrying an extra hour's petrol on board, a weight shall we say of 120 lbs. Now supposing the pilot encounters an average head wind of 25 m.p.h., which is quite a common occurrence in many parts of the world. This will reduce his forward speed to 75 m.p.h., in other words the journey will take an extra 2½ hours, and he will be in the air 12½ hours. Instead of carrying 120 lbs. of extra petrol it will be necessary to carry 360 lbs. of extra fuel that might never be needed in still air or a following wind.

Compare this case with a short distance flight of shall we say three hundred miles. Here with a cruising speed of 100 m.p.h. against a head wind of 25 m.p.h. an extra petrol supply for only 45 minutes would be needed, the weight of which on our previous basis would only be about 90 lbs.

I have mentioned this point because long non-stop flights are so very uncommercial, and up to the present the only reason that they have been adopted from a commercial point of view on aeroplane hire services is to get over the difficulty and time lost by landing on various aerodromes and refuelling.

The question of refuelling is purely a matter of ground organisation and to-day, even on the best of aerodromes in Europe, it is hardly possible to land, fill up and get away again in under the hour. There are many reasons for this, but I will not enumerate them, and no matter what aerodrome managers may say, the job should not take a quarter this time. As proof of this I would quote the King's Cup Race of 1924. Competitors were allowed to land where they liked, and for every such landing were allowed ten minutes on their handicap. At the outset much criticism ensued in which it was estimated that no machine could fill up in that itme. But when we got down to the job and made proper organisation for it, we discovered that with the right sort of petrol pumps and men who understood their job, it was possible for the machine to be in the air one minute, to land, come to a standstill, have 80 gallons of petrol pumped into its tanks, and be in the air again before the end of the next minute. This was actually done and bears thinking over very seriously.

If it is possible to refuel an aeroplane in two minutes, whatever use is there in a long non-stop flight, because apart from the increased amount of extra fuel that must be carried in a long non-stop flight to counteract the emergency of head winds, it must be remembered that an aeroplane with shall we say 10 hours petrol on board is a very inefficient or shall I say uncommercial flying proposition.

From all these foregoing remarks it would be obvious for anyone to see how important a part good ground organisation will play in the development of aviation. The main thing in all flying is speed and if this is so why, after having gained hours of time by the means of flying from one place to another, waste it all again by some inefficient service on an aerodrome?

I cannot emphasise too much the importance of completely revolutionising

the existing modes of refuelling and dispatching of aeroplanes from our present day aerodromes.

We have the antiquated method, firstly, of pouring cans of petrol into a filter through a hole in the top of a tank. Surely nothing could be more crude. Or possibly we may have a pump that with a strong man puts petrol in slowly in 5-gallon measures through the same hole in the top of the tank. Surely in these days of modern engineering it should be possible for a machine to land on an aerodrome within 20 yards of a given spot. From there a flexible pipe could be fitted by a quick attachment to a valve at some accessible and convenient spot on the aeroplane and petrol under pressure could quite easily be put into the tanks at 50 gallons a minute or more, so that it would be possible to run an express aeroplane service on a 1,000-mile run, landing four times and spending in all not more than 20 minutes on the ground.

In this proposition there is no great development, for it could be done to-morrow if only those in charge wished to organise it so.

One of the great difficulties of long non-stop flights is that of the varying changes of weather conditions, owing to the fact that the huge distances covered very often go over varying depressions, in fact from one weather zone to another, for in Europe it would be difficult at most times of the year to go in a straight line for 1,000 miles and meet with the same weather conditions the entire way. So, therefore, unless there is an elaborate system of wireless communication the machine which lands often would have the advantage of picking up weather reports of conditions ahead.

Another point to be remembered on long non-stop flights is that even for the most hardened it is not good for the passengers, and none would do it for pleasure and I am sure very few out of necessity. Another great difficulty with a long non-stop flight is the question of maintaining regularity, because it will always be more difficult, at least for some time to come, to keep a machine in the air informed of weather conditions and troubles that may be ahead than to inform the machine that is constantly landing.

Before closing on this particular question I think it would be best to make some reference to the effect of the long non-stop flight on the pilot. From my own personal experience on such occasions, I have always noticed that the first half-hour of the flight always seems the longest. Possibly this may be due to the thoughts of the hours of flying that are still ahead and that one has only passed a fraction of that time up to the present. After four or five hours continuous flying, apart from the fact that the pilot may become a little fidgety, usually he does not notice any undue strain, and can generally carry on without any desire for food, and on this point I always imagined that the pilot was possibly fed by the oxygen in the pure air in which he flies.

My own longest non-stop flight was from London to Madrid, 9 hours 40 mins., at the end of which I was quite fresh and able to run about and attend to my refuelling, and then carry on for another four hours to Tangier. I have come to the conclusion that the most fatiguing thing of all in flying is worry; and secondly, rough weather. Worry depends a good deal upon the individual pilot, especially where the pilot has a vivid imagination. I suppose that worry in piloting can be put into two kinds, firstly, worry caused by lack of confidence in machine and engine, and a very common worry of whether one's destination can be reached on the petrol supply, or possibly the difficulty of navigating and finding one's way. I think that as time goes on, with improved aircraft, most of these worries will be banished, especially the dread of engine failure causing a forced landing.

With the three-engined machine the pilot is confident that it is 1,000 to 1 chance against all three engines failing at the same moment, so that he is always

sure of some h.p. to get him on to the next landing ground in safety. And I can assure you that this knowledge is a very happy thought in the mind of the pilot when he is on his job in the air and I am sure will do much to lengthen the flying years of any professional pilot.

The only other worry that the pilot has is that of encountering bad weather, and here again the thought of engine failure will often retard a pilot from carrying on owing to the fact that he may not think it safe to fly at a few feet over the tree tops, or on the other hand to ascend above the clouds and fly in clear atmosphere where the intermediate ground between him and his destinations may be covered in fog. While dealing with the subject of weather, possibly the most fatiguing type of all flying is that of piloting through gale swept and bumpy weather, when one may not only have all the previous worries mentioned, but combined with this the difficulty of keeping the machine on an even keel and the continual physical exertion of doing so. However, as the last named case is rare, it is not worth dwelling on too much as it will not retard the general development of our transport.

Possibly at this point I might deal with the subject of navigation. The pilot, while piloting, can never be a real navigator, because although it may not be a mental impossibility to do the two, it is a physical impossibility, because he only has one pair of hands and he would certainly need two to do the two jobs. However, I maintain that the navigator should most certainly be a pilot, for no one is more fitted to navigate an aeroplane than a qualified navigator who has had years of experience as a pilot. And possibly in the future the stepping stones in the pilot's profession will be second pilot, first pilot and commander navigator. The commander navigator of the future big air liners will have had years of experience in piloting a machine over a particular air line, and he will be in charge and navigate the liner. The first pilot will no doubt take the aeroplane off the ground and put it on its course in the air, when it will be taken oven by the second pilot. In moments of emergency a first pilot may take the controls as he will on sighting the next air port and bringing it into land.

My own system of navigating on long distance flights is purely one of dead reckoning combined with map reading, using the map to check up drift. A very good system on a very long non-stop flight of navigating between two points is to draw a line on the map between those two points and then take the compass bearing with a protractor. Having allowed for variation and deviation, and having ascertained one's magnetic bearing and set the compass accordingly, one sets off on the bearing indicated. After the first few miles one locates the first object on the map that the line has been drawn through, and if one passes right over this object then the course is free from drift, but if it is a little to the right or the left then one must allow a few degrees to compensate this. After a few more miles one checks up again and possibly it may be found out that too much has been allowed for drift. However, after about 20 or 30 miles it is quite simple to find out one's correct bearing, allowing for drift, and by carrying on this course it is quite easy to hit up the destination by continually checking up the position by the line on the map.

Of course there are times when it is impossible to adhere to this method, for owing to the fact that high contours may be in one's path, and low cloud may be right down on them, it may be necessary to deviate from the straight line, and when flying in Europe, owing to our varying weather conditions, such a situation can easily develop with very little warning. It may then be necessary to follow landmarks on the map, or more often follow the lower contours on the map, thus avoiding the high ground covered in cloud. These conditions are very common in Europe, but even so one must not forsake the compass. Very often the only way to ascertain one's exact position on the map by locating landmarks with the map is by checking up the direction of the landmarks, as roads,

railways, rivers, etc., on the ground beneath with the same landmarks on the map, by the compass. It is quite possible to imagine that one is following possibly a river which one thinks has been located on the map, but on checking up with the compass it is found that whereas the river on the map is running from east to west, the river on the ground beneath is flowing from north to south. So therefore one depends upon the compass almost every moment one is flying.

There may be two or three exceptions, such as following a coastline which may be very straight and quite obvious, and similarly a river, but chief of all the exceptions is desert flying. In the case of desert flying, owing to the fact that there are no landmarks whatsoever, it is necessary to abandon the compass and religiously follow a track so that in case of emergency one would be able to follow the same track to safety and help and in the same manner help could come to one's aid.

Now we come to the question of long distance flights in the nature of aerial tours wherein the machine will wander from one country to another visiting points of interest, or long distance survey flights across the world.

Possibly these flights are the finest test for both machine and engine that it is possible to have. From my own experience one can fly a machine round an aerodrome for years and really get to know little about it, for it is not until one takes that same aeroplane out into the blue across the world that one begins to find all its faults and snags. In the precincts of the aerodrome at home there are thousands of little difficulties which are daily corrected automatically and everyone seems to forget all about them. But when one pushes out into the blue and gets away from organisation facilities and service, it is then that one finds the true worth of any aeroplane or aero engine.

For general touring work and every-day long distance flights it must be borne in mind that an engine is required in the early days of aviation that will run on any old kind of fuel and lubricant that can be found available. On the other hand, when special supplies are laid down, these difficulties are eliminated.

In comparing my two recent flights, namely, the one to Rangoon and back, and the other to Cape Town and back, the outstanding difference between these two is the fact that whereas the flight to Rangoon was accomplished on a D.H.50 aeroplane with a 230 h.p. Siddeley Puma engine, the flight from London to Cape Town could never have been accomplished with this apparatus. That is why we had to instal extra h.p. in the form of a Siddeley Jaguar engine to do the job. This was mainly due to the high altitude aerodromes of Central Africa.

While on the subject of rarefied atmospheres, I suppose there are three ways of getting over the difficulty. One perhaps is by light loading, the other is by extra h.p., and the third is by constructing huge aerodromes. From my own personal experience I think the best course of action is to adopt some of each of the last two courses, namely, construct a machine with about 35 more h.p. and an aerodrome double the usual size—shall we say, a good 1,000 yards square? I have found on long distance flights when journeying across the world that providing one has sufficient sleep it is possible to keep up six to eight hundred miles per day from the viewpoint of physical fatigue, and that after the first two or three days one gets settled down to this mode of existence, and instead of becoming fatigued, is better able after two or three days' running to carry on at this rate than he was at the start. Of course, this refers to fairly straightforward flying, and not carrying on through extreme adverse weather conditions when the routine of the daily schedule becomes upset.

I notice that in time, if one takes it methodically and regularly, one gets used to doing these long flights, hour after hour, and day after day. The first two days give the greatest trouble. Of course, I am not allowing for adverse

weather conditions, which, more than anything else, produce fatigue. Worry is another factor which will produce fatigue.

Perhaps now I ought to tell you something about the two big flights we have done in the past eighteen months, and the first matter I should like to deal with in this connection is that of organisation. Some people imagine that it is merely a question of flying, but it is not so; it is a question of planning out the flight, and organising it, and that is the most difficult part. The actual flying is really the simplest part of the whole job, although as a rule you get more credit for that than for anything else. In the organisation of a flight such as that from London to Cape Town there are hours and hours of work to be done in planning before starting, and there are miles of correspondence. You have to contemplate what conditions you are going to meet and how you are going to battle with them; there is the selection of the type of machine for the job, the putting down of supplies, the arranging of aerodromes, and then carrying along the route you have thought out.

One of the difficulties on these long flights is that of flying from one place to another without knowing the country ahead, and without any knowledge whatsoever of weather conditions. At every place you go to you get varying accounts. One man will tell you a tale as to what the weather will be, and you go to bed at night thinking of a storm which will bring you down to earth at once. Another man tells you that you will have perfectly fine weather, and that you never get bad weather at that particular time of the year. Yet all these people have lived in the place for years. What you have to do, therefore, is to inquire from everybody, and then use your own common sense, draw your own deductions, push out on the journey and find out what are the real conditions. On my outward flight to Cape Town I was very nervous. Before travelling from Tabora to Abercorn—it was in the rainy season and I had heard tales of terrible downpours—I asked a man what sort of visibility one had there. He said: "It is very bad at times; you cannot see that hill over there." I asked him how far away it was, and he said it was about ten miles. I also asked him if there were low clouds there, and he replied that there were sometimes, but I could not find out how low they came.

I had to go over a high escarpment on my way to Abercorn. I set out from Tabora and had to fly over dense jungle, about 200 miles of forest, a depopulated area with no tracks and no life. A quarter of an hour after starting I ran into a cloud bank. The aerodrome at Abercorn was at a height of nearly 6,000ft. above sea level, and I had to pass over an escarpment which was about 8,000 or 9,000ft. above sea level before getting there. When I came to the cloud banks I did not know what to do, and it was very worrying. I had not a full load of petrol, and there was the consideration that if I went on much longer it would be too late to turn back. However, I went on and on, but eventually the clouds became thicker, and at the last moment I decided to turn back. I had not the faintest idea, apart from the compass course, where we were. There had been very little wind, and it was a dead reckoning; I had to turn back on the reverse bearing, but I hit up Tabora dead on, and landed. It is a terrible waste of time to fly for an hour and a half in one direction and then to fly back over the same course. That night I worried as to what would happen next day, but the weather turned out to be fine, and we got straight through to Abercorn.

On the return journey, after we left Abercorn, we ran into heavy banks of clouds on the escarpment. I knew something about the country on this occasion, however, and mounted over the top of the cloud, flew above it, got beyond it, and came down beneath it on to the same level plateau from which we had turned back when on the outward flight. Had I known the country on the outward flight I should have gone above the cloud and got back on to the Abercorn Plateau. On the outward flight neither I nor anybody else knew the country, there were no weather reports, and those at Abercorn did not know that we were coming,

because they had no telegraph. Even in those parts where there were telegraphs, however, messages sometimes took three days to reach their destination, but as the journey there took us only about three hours, they were of no use. Those were some of the conditions with which we had to contend.

Another great worry on a flight of this description is the fact that you cannot afford to have any trouble whatsoever, because assistance might be miles away. You cannot afford to have trouble even on an aerodrome, because spares are limited, there are no workshop facilities, and you cannot afford to take chances. You have to exercise very special care from start to finish in order to avoid trouble. Some parts of the route from London to Cape Town are the worst I have ever known, from the landing point of view, especially from Mwanza to Bulawayo, or possibly Palapye Road, a distance of 2,000 miles or more, where, over perhaps 90 per cent. of the journey, it would be impossible to land without a crash, and a very severe one at that. The country consisted of swamps and dense forest, so that one had to rely upon the engine over the entire distance. From a flying point of view it was strictly uncommercial—not that we were grumbling, because the flight was a pioneer flight. We stated in our report, however, that such a trip was not exactly a practical air route, at least in that part. On the other hand, as soon as we got to South Africa the conditions were the reverse. It was possible to land anywhere we liked at any moment. It was also much simpler in Egypt, where we could land on the edge of the desert, near the Nile, almost at any time.

Another thing that impressed me during the flight was that aircraft must be able to exist without the protection of sheds or hangars. As we know flying at present, we have a little flight round the aerodrome, and then we put the machine in a hangar and protect it, and so on. That is all very well, but when you get out on to the world routes, aircraft must be more of the nature of a railway carriage or a motor car, and must be able to withstand any weather conditions. The machines that I have taken to Rangoon and Cape Town have stood it very well indeed. The extraordinary thing is that the very part which the ordinary lay person thinks will not stand the heat or rain, namely, the fabric, stands it better than anything else. I do not understand now why the fabric does not fail, when it has to stand the heat of the sun at 160 or 180°F. for fourteen or sixteen hours a day, and then the cold at night! These conditions seem to make not the slightest difference, and in fact the fabric appears to be one of the strongest parts of the machines. I believe it is due entirely to dope, however, which, I understand, the makers of all-metal machines are putting on the metal.

There is one point which, perhaps, will hardly interest the Royal Aeronautical Society, but it is one worth mentioning. I have come to the conclusion that these long flights are wonderful health cures. Although one might be very run down in health, one can set off on a flight, and work sixteen or seventeen hours a day very often, and sometimes eighteen hours a day, for two or three months, and thrive on it, providing one has plenty of actual flying. It is only when one stops flying that one gets run down. I do not know the reason for it, but it is something which the doctors might perhaps look into.

I think the great future of long distance flights is not as we know them to-day, but in the direction of a system of relays. We know long distance flights to-day more or less as stunts. We set out with a machine and go as hard as we can to some particular spot, or we may go somewhere to carry out a survey, but real success in long distance flying, in my opinion, is going to be achieved by the relay system. It is not merely a question of flying, say, from London to Australia; that is not the real object of aircraft. The real object is to transport something, such as passengers, goods or mails, quickly. The relay system, however, seems never to have been properly considered, and it is here that the question of ground organisation comes in. There are heaps of designers to-day

working on machines which are going to fly enormous distances, we are told, day and night, without landing. I do not know how they are going to get down to it, because it means that you have to carry an enormous load of petrol, and while you are carrying petrol, you cannot be carrying passengers. Why not look at it in a more simple way, and do the obvious thing, namely, speed up the ground organisation, so that you can run a relay of machines, landing at every 200 or 250 or 300 miles, with five-minute stops? It could be done to-morrow; the passengers would have time to stretch their legs occasionally, and then carry on again. The finest thing would be, in my opinion, to find out how quickly we could fly across the world by this system of relays, and how quickly we could transport a particular packet of mails across the world.

There are one or two important lessons to be learned from the flight from London to Cape Town and back. The chief of them all is that an air-cooled engine is a practical proposition. I think everyone seemed to doubt it at one time, but it really is a practical proposition, and I think the data we brought back will not add very many improvements to it, although it may solve one or two little things which I am not quite certain about. It may interest you to know that our engine ran in temperatures of 118 degrees in the shade and 160 degrees in the sun, perhaps more. The hotter the atmosphere, the better the engine seemed to run. The highest oil temperature we had was 80 degrees, and the oil in the radiator was hotter than the oil that was coming from the engine. That may be rather alarming. All the way through the flight we had a so-called oil radiator, which gave us, in all atmospheres, a radius of five degrees, but that radius was not big enough. Mr. Walker, of the D.H. Company, humorously remarked that if we had had a bigger radiator, when we got into a hot place the oil would be boiling in the radiator. During the very hot weather in the Sudan we had temperatures of 80 degrees in the engine and, curiously, 90 degrees in the radiator. That only lasted for about ten minutes, however, and by descending to about 7,000ft. we reduced it to 70 degrees in radiator and 75 degrees in engine, whereas the oil temperature in South Africa, on the equator, was usually about 65 degrees radiator and 70 degrees engine. It may surprise you to know that the equator was not the hottest part of the journey. The two hottest places were the Sudan, from Khartoum to Mongalla, and Kimberley, in South Africa. It was extremely hot in Kimberley, and there we had our first experience of being really distressed owing to heat.

On the way out, through the Sudan, the heat was not so great and we did not experience difficulty, but when we got to Kimberley we discovered something about cabin ventilation. I can assure you that some very interesting data have been collected in that connection, and that machines for the tropics in future will have some very drastic method of getting cool air into them. I do not quite know, however, how we are going to get cool air into the cabin when a hot wind is blowing. The best thing to do in order to keep cool in such a wind is to stand still and just be fanned by this hot air. If you walk against the hot air, you become a little warmer; if you drive against it in a car with the screen open it is warmer still; and if you drive against it in an aeroplane at 100 m.p.h. it is simply burning. Those hot winds occurred only in certain places, however. In the Sudan I found that by rising to a very high altitude we were able to get out of the hot wind.

With regard to the getting-off difficulties, on the high aerodromes the relative density of the atmosphere varied considerably, not so much with the altitude but with the place. Right down to Mongalla one noticed very little difference in the performance of the machine. It is true that the performance of our machine at Stag Lane is very much above what it is, say, at Mongalla, but one does not notice any appreciable difference; and it was not until we took off from Mongalla and landed at Jinja, at Victoria Nyanza, near the equator, 4,000ft. above sea level, that we noticed the difference. At Jinja I prepared to land in the ordinary

manner, but some natives ran across the track. By instinct, I side-slipped the machine in, and landed short, in order to avoid them, but I had forgotten the altitude of the aerodrome, and, instead of getting a float when I pulled up, the machine simply fell through the air and came down rather heavily. The undercarriage stood it, however, and after a little adjustment we were able to carry on, but it was the heaviest landing we had, and I do not think the undercarriage would have stood much more of a bump. After that we decided that, natives or no natives, we would always land straight ahead.

At Kisumu I discovered there was a prevailing down-current. The surface of the aerodrome was hard, but it took us longer to get off that aerodrome than to get off others which were higher. At Tabora we had a soft aerodrome, but we got away all right. At Abercorn, where the altitude of the aerodrome is 5,500ft., we took off with a full load in 300 yards; in fact, we had an overload, which brought the machine to about 4,500 lbs. We got off very well at Ndola and Livingstone, and then we came to Bulawayo. You have probably heard a good deal of talk about the difficulty of getting off there. The trouble was that we had to take off across the racecourse and there was not sufficient run, the maximum being about 400 yards. On such flights, if I cannot get off when half-way across the aerodrome, or at least if I am not certain that I can get off before it is too late to shut off, run and stop before reaching the far end of the aerodrome, I simply do not carry on. One cannot run the risk. At Bulawayo I reached the point where I could see that if I did not shut off at that second—assuming I did not get off—I should not have enough room to pull up to a standstill. I tried a second time, and the same thing happened; I ran 150 or 200 yards, but the machine was not going to shift quickly enough. Then I took off some of the load, and bounced off in about 150 yards. There was a lot of talk about us not getting away from that aerodrome, but on the return journey we got off the same aerodrome, with the wind in the right direction, with full load on board, and got away fairly well. We discovered, however, an interesting fact. Whereas usually the aeroplane would cruise comfortably with maximum load on board at 1,500 r.p.m., and would even climb at that, in Northern Rhodesia I could not maintain my height at 1,500 r.p.m. That is extraordinary, and I have suggested that it would be worth while to send out the meteorological service to investigate the atmospheric conditions of Northern Rhodesia, and to find out the cause of this obviously rarefied atmosphere.

In South Africa the get-offs were quite easy, and not nearly so difficult as people were led to believe at home before we started. The people there are getting off with the same machines and the same loads as we have here. At Johannesburg, with a full load on, at 6,000ft. above sea level, we got off well.

At Tabora, on the return journey, we had difficulties because the earth collapsed. We landed and ran a few yards, but when we came to a standstill one wheel sank to the axle. In getting off again we sank four times, and I can assure you that the get-off there was the only one in which I felt I was taking chances. We simply staggered off, and we had the feeling of the machine rising with the wings flapping in the air, because there was no control. However, we got away quite all right.

Another difficulty we had was a sandstorm. An engine will run through a sandstorm. You can take practically handfuls of sand out of the air intakes, but it does not seem to stop the carburettor. I do not suppose that is really very wonderful, because the carburettor of an engine consuming twenty gallons an hour is something like a hose pipe. On the other hand, we were disturbed about bearings, because the sand in Egypt is a good grinding compound. During the sandstorm we had to forsake navigating and follow the Nile. What is more interesting is that, although people tell you that sandstorms reach an altitude of only 1,500ft., I went up to 12,000ft. and the sand was almost as thick there as it was at ground level; I could not get out of it, but I should think that at about

15,000ft. I should just about have cleared it. There was not visibility ahead or at the sides, and all we could do was to look directly beneath the machine, where there was a hazy view of the Nile flowing through just nothing at all. That is how we flew.

It was at this point that I had one of my worst shocks, because if we had lost ourselves in the desert it would have been very serious. We should probably not have known which side of the Nile we were on, and we should not have known which way to go for help. I suddenly realised that this shadow beneath the machine, which I was following, was not the Nile, and it came as a great shock to me. We came down from 12,000ft in about two minutes. We did not know which way to turn, but I thought we must be on the east of the Nile, so we flew west. I then noticed a dried-up river course, and followed it. Fortunately, it led to the Nile, and after that, dust or no dust, we flew at a height of about 20ft. over the Nile. Then we followed the railway line which runs through a yellow sand desert from Abu Hammad to Wady Halfa. When I first went over there I thought it was the simplest flight of the whole lot, there being mountains, a railway, and perfect visibility. But when you have a visibility of about 700 yards at the outside, there being no mountains to see, and nothing but yellow sand and the railway track and telegraph poles running along it, it is a different proposition. The only thing to do was to fly along the railway line at a height of about 20ft. We flew along the right-hand side of the line, so that the line was on the left of the machine. It was dangerous to look over the right-hand side of the machine, because the atmosphere was full of dust and merged into the desert, and you could not tell which was desert, which was sky, and which end was up; the only way to keep level was to look over at the railway line and follow the telegraph posts. Just as, when one looked out of a railway carriage window, the telegraph poles alongside the line appear to merge into a blur, so the poles in this case tended to merge into a blur, and a great deal of concentration was needed in order to avoid that. We carried on for about 200 miles, and at last got through into country where there were mountains, bits of bushes here and there, and so on, to break the monotony.

The only awkward time we had was when crossing the Mediterranean to Crete and on to Athens, when we had to fly 450 miles over the sea. Here I wished I had had a real navigator with me, because I had to start off on a dead reckoning and carry on right the way through. Visibility was very bad on every hand, and after flying for four hours against a head wind, out of sight of land, we were getting rather disturbed, because Crete had not turned up. The waves were terrific, but we carried on, for we had an eight hours' supply of petrol, and we felt we must hit something eventually. It is always best to hold on in those circumstances; your compass is bound to bring you out. At last we saw the island of Cytheria, so that we had really followed a good compass course. We came to the mainland of Greece, and flew round Cape Malia, getting on to the lee side of the mountain there, with a strong west wind blowing. When one does that, of course, one gets violent down-currents, which cause bumps. My experience is that the worst bumps are caused by down-currents off mountains, and I can assure you that this was the worst bump I have ever experienced, although it only lasted for two or three minutes. Elliott also said it was the worst he had ever had. We were simply flung down from 1,000ft. to within about 200ft. of the water. Elliott and Emmott looked rather humorous, because their heads were stuck to the roof of the cabin. The machine fell so quickly that the petrol could not fall down the feed pipe, with the result that the engine temporarily cut out. It picked up again, however, and I steered for the open sea, and in about three minutes it was all over. When I flew round the mountain in the first place I had not thought about it. I came quietly round the corner, not thinking that the wind was so strong, and we were drawn into this violent wind current in a few seconds.

Discussion

Colonel Edwards: I also should like to congratulate Mr. Cobham on the magnificent flight he has just completed, and for all the previous flights he has made, which have added to the lustre of and have done so much to help British aviation. What we have heard to-night emphasises and impresses upon us even more, possibly, than we imagined before the grit and the pluck which was required to carry the flight through. Mr. Cobham has laid particular stress on the necessity for ground organisation, and it is a point on which I feel very strongly, because it is so vitally necessary for the development of commercial aviation. We have to save time on the ground, because it is useless to achieve a great speed in the air if we are going to waste time on the ground, and that is one of the directions in which progress must be made. The three-engined machine, I think, will play an extraordinarily important part in the development of commercial aviation, not only in the direction of increased regularity, but in reducing costs. Again, Mr. Cobham has undoubtedly done a very great service to civil aviation in giving us very definite proof of what the air-cooled engine can do. If it can stand up to the conditions imposed upon it in the flight to Cape Town and back, where it had to eat dust and sand, and had to run for many hours, we cannot want anything better than an air-cooled engine, and the information obtained will help us to solve one of the many problems to be faced in commercial aviation.

Wing-Commander Cave-Browne-Cave: I was very interested in Mr. Cobham's remarks about ground organisation, and in Colonel Edwards' remarks as to its importance in civil aviation. I submit that it is at least equally as important in connection with Service aviation, and a great deal of attention is being given to the development of really satisfactory ground gear for filling up aeroplanes and re-arming them quickly. Considerably more attention might perhaps be paid by designers to improve their machines in this respect. I was very interested also in Mr. Cobham's reference to a system of very fast relays. It is quite true that the important thing is the speed at which we can get the passengers and mails from one end of the journey to the other. But such a system of relays calls not for quick refilling arrangements, but for quick transfer of mails and an agile breed of passenger. There is one advantage of long flights which I should like to mention. The pilot can avoid regions of unfavourable weather and may be able to derive assistance from a depression which would cause delay if the course had to include certain intermediate aerodromes over which there was contrary wind or thick weather. If the flight is a long one, a diversion to gain this advantage need not greatly increase the distance covered and may decrease the air miles flown. This is exactly parallel to problems we have been working out in connection with airship routes, and we consider there is very great advantage indeed in the comparatively long flights which the airship can make. How much flying under this quick relay system can a passenger stand? I think that passengers in the restricted cabin space of an aeroplane for long lengths of time will find the journey vastly more trying than very much longer continuous flights by airship, where it is possible to move about. Is it preferable to go from London to the Cape through all the climatic conditions Mr. Cobham has described with the system of quick relays, or to go by airship along a western route mostly over the sea and calling only perhaps at Madeira and Ascension?

Mr. Alan Cobham: With regard to passenger traffic, I am sure that, with proper organisation, a machine could be on the ground ready to take over passengers from another machine, which would land beside it, and could get away in a very short time. My experience of the average passengers on trams, 'buses and trains is that they can move as quickly as anybody else. You can see them get a move on at the stations, and on the tubes the trains come in, set down their passengers, and are out again in two minutes, without any trouble.

So long as the operators are on an aerodrome ready to get the baggage out of one machine and put it into another, the change can be effected in five minutes. I am talking of journeys of 600 or 700 miles a day, which is quite enough for the passenger, and am not referring to long relays for carrying mails. There, of course, the passenger does not come into it, and the mails cannot grumble, so that it is simply a question of hauling the mails out and putting them into another machine. There must also be means of re-fuelling rapidly, so that a machine could do 600 or 700 miles, with one stop for re-fuelling, and at the end of the 600- or 700-mile jump another machine would be waiting to carry on. With regard to the amount of travelling which the passengers could stand, I should think that, providing the weather is not too bad, they could stand, when they get used to it, anything up to 500 miles a day, and perhaps more. I think a certain amount of air sense has to be acquired, and also, if the cabins were bigger, and there was less noise, they could stand far more than they do to-day. With regard to deviating from the straight course, that is all very well for airships, about which I know nothing, but with aeroplanes you cannot afford to deviate. If you have a journey of 1,000 miles, you have to take the straight course, and cannot afford to carry an enormous amount of petrol to allow for deviation at the expense of the load, be that load passengers, mails, or anything else.

A SPEAKER: Would it be possible to re-fuel and transfer mails in the air, so that it would not be necessary to bring the machine to the ground?

Mr. COBHAM: No doubt that would be possible, but I am talking of the present state of aviation. Is it worth it, if you can re-fuel and transfer mails on the ground in five minutes? In the King's Cup Race we proved that re-fuelling could be done in two minutes, and if it can be done in that time on the ground, it is hardly worth while doing it in the air, at any rate for some years to come. By means of pressure we could put in fifty gallons or more of petrol per minute.

Major MAYO: One thing that seems to me so remarkable about the flight which Mr. Cobham has just completed is that he was able to carry through from start to finish without any of the accessories that are available for the regular transport services such as wireless, meteorological services, and so on. He can have had very little information as to the state of the weather and other conditions on most of the stages of the flight. In view of this it was a brilliant achievement to carry the flight through without a hitch. I wish we could have the benefit of another lecture by Mr. Cobham later on so that he could give us further details of this flight. For instance, he has said practically nothing about the final stages of the return flight; to my mind, the final dash from Sollum to Croydon was most remarkable, and the speed with which it was completed indicates extraordinary determination on his part. The fact that the engine had been flying through bad conditions for such a long period without overhaul in a workshop makes that final dash all the more creditable, and I am sure that we all congratulate Mr. Cobham most heartily on his achievement.

Mr. COBHAM: The last part of the journey, from Athens to London, was done quickly because we were able to get away with it. It is quite simple to carry on, and you can keep up 700 or 800 miles a day in two jumps; it is simply a matter of doing it methodically. We had done the same thing further south, and we could have come home at that rate in about nine days, or perhaps eight, but we were held up by tropical rains for a day at Mongalla; we were held up for half a day at Abercorn; for a day at Khartoum, owing to a sandstorm; then at Cairo, through gales; and again at Sollum. We flew, for instance, from Abercorn to Kisumu in one day, a distance of nearly 800 miles, and on the following day we flew nearly another 900 miles to Malakal. That was another episode similar to that from Athens to London, but it was further away, and you did not know about it. It was simply adverse weather conditions, which we did not meet on the outward journey, which prevented us putting up a startling

show from the point of view of speed on the return. You must have system on a flight such as this. We had to go to bed early and get up before daylight, and as soon as there was sufficient light we were in the air, and making for the next destination. When we arrived there, Elliott was left free to look over the engine, whilst I was making the general arrangements and supervising re-fuelling, and in about an hour and a quarter we were in the air again. At the next stop we went through the same procedure, went to bed early, and left as soon as it was light enough in the morning. We had coffee in the morning, a scanty lunch, and a meal in the evening.

The CHAIRMAN: I was particularly interested in Mr. Cobham's statement that a man can make very long flights without exhaustion when he has confidence in his machine. I think it is the experience in all sorts of occupations that in the absence of worry there is very little exhaustion; but it is promising to hear that anyone can free himself from worry in aviation. A point that comes out very clearly is that the development of civil aviation is so closely wrapped up with the development of wireless communication. You must have rapid and certain communication from one aerodrome to another, and you are going to get that in the next few years. It is obviously important to get accurately meteorological data, but we must not underestimate the difficulty of getting it. Pioneers always have to do without it.

I should like now to express our thanks to Mr. Cobham for having come here at such short notice, and for having delivered one of the most fascinating lectures that we have listened to for a long while.

The vote of thanks was carried with acclamation, and the meeting closed.

AIRSCREW VIBRATION AND GEAR STRIPPING

BY CAPTAIN J. MORRIS, B.A., A.F.R.AE.S.

Mr. J. D. Siddeley in a paper on the reliability of aircraft engines in the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY for March, 1925, says under the heading Reduction Gears: "The inclusion of this component has been responsible for limiting seriously the degree of reliability of the power unit. Considerable progress has been made, but the difficulties have by no means been solved. A stage existed when this component controlled the period between inspection and overhauls on the power unit. Improvements in the method of manufacture, particularly as affecting tooth form, have been responsible for a very considerable increase in the degree of reliability, but it is suggested that it represents one of the chief factors controlling the standard of reliability of the power unit as a whole."

This statement is sufficiently serious; coming from so great an authority on aircraft engines it compels attention and investigation.

It would appear to the writer that gear troubles in aircraft engines do not necessarily arise from the gears *per se* as there are certain geared aircraft engines in which no special trouble has ever arisen from the gears. Gear failures, however, will almost invariably occur with the crude method of gearing in current practice, that is, with a single spur wheel on a crankshaft engaging with a single gear wheel on the airscrew shaft. And for this reason the horse-power of the engine is transmitted by an unbalanced force of relatively great magnitude and which force is, moreover, not uniform but rhythmic.

The torque of an internal combustion engine is not steady but is periodic, the fundamental frequency being governed by the number of cylinders of the engine. The mutual force between the gear wheels acquires this periodicity and so we have acting on the airscrew shaft an unbalanced lateral force of frequency equal to that of the engine torque. Now the system, airscrew—airscrew shaft—airscrew shaft gear wheel will be forced to vibrate during rotation with the frequencies of the applied forces. If then at a running speed there is synchronisation between the free vibrations of the airscrew system and the frequency of a forced vibration acting on the system, there will be resonance with consequent failure at that speed if maintained.

The forced vibration resulting from the mutual force between the gear wheels is not the only one which may prove harmful. In general the airscrew of an aircraft does not work in a uniform air field owing to the unsymmetrical disposition of the various parts of the aircraft. So that if we have a two-bladed airscrew a particular group of conditions will recur twice during one revolution of the airscrew; and for a four-bladed airscrew four times in one revolution. The effect of this is to set up a forced vibration on the airscrew system of speed twice that of the airscrew shaft in the case of a two-bladed airscrew and four times for one with four blades.

A useful investigation thus presents itself and in this paper an attempt is made to deal with this important problem. Strange as it may appear the difficulties are not mathematical. The correct solution of the problem depends on something fundamental, something which goes to the very roots of engineering, for it resolves itself into what is meant by a rotating shaft.

Hitherto the underlying conception of shaft rotation has been that the shaft with loads (if any) revolves bodily, with the imparted angular velocity, about the

axis of bearings, and this has been taken as the basis by practically all investigators of shaft vibration problems. Its adoption has resulted in a very marked disagreement between theory and practice. For example, it is notorious that a shaft will run steady above its whirling speed and yet according to the theory by which the whirling speed is usually arrived at stability should be impossible above it. This vital non-agreement has either been ignored or explained away by the quite unfounded supposition that above the whirling speed different but unknown conditions arise which are inconsistent with the theory valid apparently up to the whirling speed.

This discrepancy between theory and fact was closely investigated by Professors Orr and Jeffcott, who arrived at the conclusion that when a shaft revolves each element fundamentally rotates, with the imparted angular velocity, about its own axis and not about that of the bearings. On this view not only are the correct whirling speeds arrived at, but there is complete harmony between theory and practice concerning stability above the whirling speed.

Consequently since this view of rotation most closely agrees with observation the writer has adopted it in the present investigation.

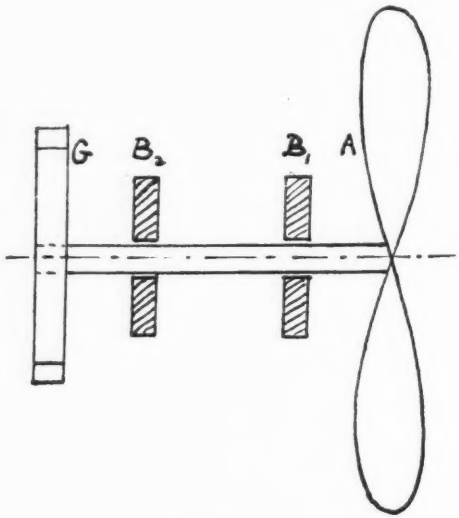


FIG. 1.

Referring to Fig. 1, let AB_1B_2G be an airscrew shaft supported in two short bearings at B_1 and B_2. Let A represent the airscrew and G a gear wheel of relatively small weight and inertia.

Suppose next in Fig. 2 PQ is the axis of the bearings of the airscrew shaft.

Let O be the displaced position of the centre of the airscrew boss on the axis of the shaft and let G be the centre of gravity of the airscrew (not necessarily coincident with O).

Let Gx, Gy, Gz be a system of rectangular axes fixed in direction in which Gz is parallel to PQ. Let GA, GB, GC be the principal axes of inertia of the airscrew which are initially supposed coincident with Gx, Gy, Gz. The axes GA, GB, GC are supposed brought into their displaced positions by

(1) A small rotation ϕ about the axis Gy in the direction z to x;

(2) Then a small rotation θ in the direction z to y about the so displaced axis Gx;

(3) And finally the airscrew is supposed rotated through an angle Ωt about the axis GC in the direction x to y.

Let x, y be the co-ordinates of O referred to an origin on the centre line of the airscrew shaft bearings, the axes being regarded as in the plane of and parallel to Gx, Gy. Also let $OG=h$.

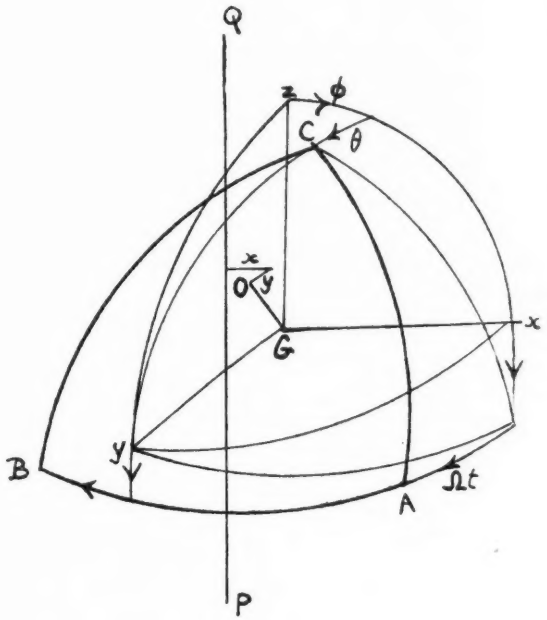


FIG. 2.

If ω_1, ω_2, ω_3 are the angular velocities of the system of axes GA, GB, GC, then

$$\omega_1=\dot{\phi}\sin\Omega t-\dot{\theta}\cos\Omega t \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\omega_2=\dot{\phi}\cos\Omega t+\dot{\theta}\sin\Omega t \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\omega_3=\Omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

And the angular momenta about the same axes will be

$$a\omega_1,\ b\omega_2,\ c\omega_3,$$

respectively, where A, B, C are the principal moments of inertia of the airscrew and

$$a=A/g,\ b=B/g,\ c=C/g,$$

g being the acceleration due to gravity.

About the axis Gx (fixed in direction) the angular momentum will be

$$\begin{aligned} h_x&=a\,(\dot{\phi}\sin\Omega t-\dot{\theta}\cos\Omega t)\cos\Omega t \\ &\quad -b\,(\dot{\phi}\cos\Omega t+\dot{\theta}\sin\Omega t)\sin\Omega t+c\Omega\phi \\ &=-a_1\dot{\theta}+c\Omega\phi+b_1\,(\dot{\phi}\sin 2\Omega t-\dot{\theta}\cos 2\Omega t) \quad . \quad . \quad (4) \end{aligned}$$

where

$$a_1=\tfrac{1}{2}(a+b),\ b_1=\tfrac{1}{2}(a-b).$$

Similarly about the axis Gy the angular momentum will be

$$h_y = a_1\dot{\phi} + c\Omega\theta - b_1\,(\rho\cos 2\Omega t + \dot{\theta}\sin 2\Omega t) \quad . \quad . \quad . \quad (5)$$

If now

y_{11} = deflection of the shaft at O due to unit weight at O,
z_{11} = slope of the shaft at O due to unit weight at O,
= also deflection of the shaft at O due to unit couple at O,
ϕ_{11} = slope of the shaft at O due to unit couple at O,
$\Delta = y_{11}\phi_{11} - z^2_{11}$,
$y'_{11} = y_{11}/\Delta$, $z'_{11} = z_{11}/\Delta$, $\phi'_{11} = \phi_{11}/\Delta$,

then the equations of motion of the airscrew will be found to be

$$(mD^2 + \phi'_{11})\,x - z'_{11}\phi = mh\Omega^2\cos(\Omega t + \varepsilon) + a\cos(pt + \eta) \quad . \quad . \quad (6)$$

$$(mD^2 + \phi'_{11})\,y - z'_{11}\theta = mh\Omega^2\sin(\Omega t + \varepsilon) + a\sin(pt + \eta) \quad . \quad . \quad (7)$$

$$(a_1D^2 + y'_{11})\,\phi + c\Omega D\theta - b_1\,(d/dt)\,(\dot{\phi}\cos 2\Omega t + \dot{\theta}\sin 2\Omega t) - z'_{11}x = 0 \quad (8)$$

$$(a_1D^2 + y'_{11})\,\theta + c\Omega D\phi - b_1\,(d/dt)\,(\dot{\phi}\sin 2\Omega t - \dot{\theta}\cos 2\Omega t) - z'_{11}y = 0 \quad (9)$$

where

$$mh\Omega^2\cos(\Omega t + \varepsilon),\ mh\Omega^2\sin(\Omega t + \varepsilon)$$

is the forced circular vibration due to lack of balance;

$$a\cos(pt + \eta),\ a\sin(pt + \eta)$$

is a forced circular vibration of speed p acting on the system; and

$$m = W/g$$

W being the weight of the airscrew.

If we are dealing with a four-bladed airscrew

$$b_1 = a$$

and so

$$a_1 = a \text{ and } b_1 = 0$$

Under such conditions equations (8) and (9) become

$$(aD^2 + y'_{11})\,\phi + c\Omega D\theta - z'_{11}x = 0 \quad . \quad . \quad . \quad . \quad (10)$$

$$(aD^2 + y'_{11})\,\phi - c\Omega D\phi - z'_{11}y = 0 \quad . \quad . \quad . \quad . \quad (11)$$

In so far as the forced vibration of speed p is concerned a particular solution presents itself of the form

$$\left.\begin{aligned} x &= x_0\cos(pt + \eta) \\ y &= x_0\sin(pt + \eta) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

$$\left.\begin{aligned} \phi &= \phi_0\cos(pt + \eta) \\ \theta &= \phi_0\sin(pt + \eta) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (13)$$

where

$$x_0 = a\left[(-ap^2 + c\Omega p) + y'_{11}\right] / \left[map^4 - mc\Omega p^3 - (a\phi'_{11} + my'_{11})\,p^2 + c\phi'_{11}\Omega p + y'_{11}\phi'_{11} - z'^2_{11}\right] \quad . \quad . \quad . \quad . \quad (14)$$

$$\phi_0 = az'_{11} / \left[map^4 - mc\Omega p^3 - (a\phi'_{11} + my'_{11})\,p^2 + c\phi'_{11}\Omega p + y'_{11}\phi'_{11} - z'^2_{11}\right] \quad . \quad . \quad . \quad . \quad (15)$$

Clearly the amplitude of these forced vibrations will become infinite when

$$map^4 - mc\Omega p^3 - (a\phi'_{11} + my'_{11})\,p^2 + c\phi'_{11}\Omega p + y'_{11}\phi'_{11} - z'^2_{11} = 0 \quad . \quad (16)$$

or

$$m\Delta\,(ap^4 - c\Omega p^3) - (a\phi_{11} + my_{11})\,p^2 + c\phi_{11}\Omega p + 1 = 0 \quad . \quad . \quad (17)$$

This incidentally as an equation in p gives the speeds (no account being taken of sign) of the free vibrations of the airscrew when rotating with constant angular velocity Ω.

It can be proved that the roots of the equation (17) in p are always real and so the free vibrations are exponentially stable whatever the value of Ω.

For the forced vibration due to lack of balance we put

$$p=\Omega$$

and we find that the amplitudes of the vibration considered become infinite when

$$m\,(c-a)\,\Delta\Omega^4-\{\,(c-a)\,\phi_{11}-my_{11}\,\}\,\Omega^2-1=0 \quad . \quad . \quad (18)$$

This equation in Ω^2 gives the speeds at which the frequency of the forced vibration due to lack of balance synchronises with a free vibration of the shaft when rotating with constant angular velocity. Such speeds are called whirling speeds.

Equation (17) has only one real root in Ω^2 and is quite general for one load on any shaft in any bearings. It agrees with the solutions for particular cases which have been arrived at by other writers.

From equations (14) and (15) we observe that with $p=\Omega$ and $a=mh\Omega^2$ the amplitudes are quite finite above and below the whirling speed; further that as Ω becomes infinitely large

$$x_0\rightarrow -h$$

and

$$\phi_0\rightarrow 0$$

So that above the whirling speed the centre of gravity of the unbalanced load tends closer and closer to the axis of the bearings and the slope of the shaft at O becomes smaller and smaller as the speed of rotation increases.

To take a numerical example. Referring to Fig. 1, let

$$AB_1=6 \text{ ins. and } B_1B_2=10 \text{ ins.};$$

$$I \text{ (the lateral moment of inertia of the shaft)}=1 \text{ in.}^4$$

$$E=30\times 10^6 \text{ lbs. per sq. in.}$$

$$W=70 \text{ lbs.}$$

C (the polar moment of inertia of the airscrew)$=2.4=30{,}720$ lbs. ins.^{2}

For the shaft supported as shown

$$y_{11}=AB_1^2\,(AB_1+B_1B_2)/3EI=192/e$$
$$z_{11}=AB_1\,(3AB_1+2B_1B_2)/6EI=38/e$$
$$\phi_{11}=(3AB_1+B_1B_2)/3EI=28/3e$$
$$\Delta=y_{11}\phi_{11}-z_{11}^2=348/e^2$$

where

$$e=EI$$

For the values of the above in certain standard cases, see the writer's R. & M., No. 551 (Advisory Committee for Aeronautics), October, 1918.

Now

$$m=70/384=.18$$
$$c=30{,}720/384=80$$
$$a=40$$

Inserting the numerical values in equation (18) we obtain the quadratic

$$2505.6\,X^2-338.77\,X-1=0 \quad . \quad . \quad . \quad . \quad (19)$$

where $X=\Omega^2/e$

The real root is approximately

$$\Omega^2/e=.138$$

leading to a whirling speed in the neighbourhood of

$$19{,}450 \text{ r.p.m.}$$

Suppose the airscrew shaft in question has a top speed of 1,200 r.p.m. then there is no conceivable danger from whirling, although considerable vibration will be set up if there is lack of balance.

Theoretically, if the four-bladed airscrew were perfectly balanced (both statically and dynamically) it could not whirl at all as there would be no forced

vibration which causes whirling; but in practice it is almost impossible to ensure absolute balance particularly dynamic.

Next we will consider the forced vibration set up by the mutual action of the gear wheels, it being supposed that the gearing consists of a single spur wheel on the crankshaft engaging with a single gear wheel on the airscrew shaft. Let the gear reduction be such that the airscrew shaft rotates at half the crankshaft speed and suppose the engine is provided with twelve cylinders.

If then Ω is the angular velocity of the airscrew shaft the fundamental speed of the periodic unbalanced lateral force arising from the gear action will be 12Ω since there are twelve firing strokes to each complete revolution of the airscrew shaft.

In general the periodic forces we have to deal with are analogous to reciprocating forces which consist of a pair of equal centrifugal forces, but of opposite speeds. Thus, a primary force of

$$\beta \cos \Omega t$$

along the axis of a cylinder is equivalent to two sets

$$(1)\ \beta/2 \cos \Omega t,\ \beta/2 \sin \Omega t,$$
$$(2)\ \beta/2 \cos (-\Omega t),\ \beta/2 \sin (-\Omega t),$$

making together

$$\beta/2 \cos \Omega t + \beta/2 \cos (-\Omega t) = \beta \cos \Omega t$$

along the axis of the cylinder and

$$\beta/2 \sin \Omega t + \beta/2 \sin (-\Omega t) = 0$$

along a line perpendicular to that axis.

In general a force

$$\alpha \cos (pt + \eta)$$

along a definite axis is equivalent to two sets of components arising from centrifugal forces of opposite speeds.

So that if we have a forced vibration which is not circular, we resolve it into circular vibrations of opposite speeds. Thus, for the four-bladed airscrew considered we put

$$p = \pm 12\Omega$$

in equation (17) in order to obtain the resonant speeds arising from the gear action.

For $p = 12\Omega$ we obtain the equation

$$43{\cdot}3\, X^2 - {\cdot}05\, X + 10^{-6} = 0 \quad . \quad . \quad . \quad . \quad (20)$$

where

$$X = \Omega^2/e$$

This leads to resonant speeds in the neighbourhoods of

225 and 1,770 r.p.m.

For $p = -12\Omega$ we obtain

$$60{\cdot}6\, X^2 - {\cdot}068\, X + 10^{-6} = 0 \quad . \quad . \quad . \quad . \quad (21)$$

from which we find resonant speeds at about

210 and 1,750 r.p.m.

Since these speeds are out of the running no trouble can arise from this source for the airscrew considered.

Next consider the forced vibrations resulting from blade interference.

For resonance from this source we put

$$p = \pm 4\Omega$$

in equation (17).

For $p=4\Omega$ we find resonant speeds at

925 and 5,400 r.p.m.

and for $p=-4\Omega$ resonant speeds at

570 and 5,250 r.p.m.

Now 925 r.p.m. is somewhat near the cruising speed of the airscrew; so that with an engine with the above data there is considerable danger of failure in the airscrew system as the result of resonance arising from the forced vibrations set up by blade interference.

If now we wish to deal with the case of a two-bladed airscrew we have to find a solution for the equations (6), (7), (8) and (9). In so far as the forced vibration of speed p is concerned, a particular solution will be found to be given by

$$x=x_1\cos(pt+\eta)+x_2\cos\{(2\Omega-p)t-\eta\}$$
$$y=x_1\sin(pt+\eta)+x_2\sin\{(2\Omega-p)t-\eta\}$$
$$\phi=\phi_1\cos(pt+\eta)+\phi_2\cos\{(2\Omega-p)t-\eta\}$$
$$\theta=\phi_1\sin(pt+\eta)+\phi_2\sin\{(2\Omega-p)t-\eta\}$$

and the amplitude of the forced vibration will become infinite when

$$[ma_1p^4-mc\Omega p^3-(a_1\phi'_{11}+my'_{11})p^2+c\phi'_{11}\Omega p+y'_{11}\phi'_{11}-z'^2_{11}]$$
$$\times[ma_1(2\Omega-p)^4-mc\Omega(2\Omega-p)^3-(a_1\phi'_{11}+my'_{11})(2\Omega-p)^2+c\phi'_{11}\Omega(2\Omega-p)$$
$$+y'_{11}\phi'_{11}-z'^2_{11}]-b^2_1[mp^2-\phi'_{11}][m(2\Omega-p)^2-\phi'_{11}]p^2(2\Omega-p)^2=0 \quad . \quad (22)$$

For whirling we put

$$p=\Omega$$

and obtain the equations

$$(1)\ m(c-a)\Delta\Omega^4-\{(c-a)\phi_{11}-my_{11}\}\Omega^2-1=0 \quad . \quad . \quad (23)$$
$$(2)\ m(c-b)\Delta\Omega^4-\{(c-b)\phi_{11}-my_{11}\}\Omega^2-1=0 \quad . \quad . \quad (24)$$

That is, whirling speeds corresponding to four-bladed airscrews of moments of inertia

(1) a, a, c and (2) b, b, c respectively.

Where a is greater than b the whirling speed for (1) will be the lower.

An examination of equation (22) will reveal the fact that for values of Ω in excess of the lower whirling speed stability is impossible, that is to say, that the vibrations are exponentially unstable.

If as will very nearly be the case in practice

$$a=c \text{ and } b=0$$

equation (23) reduces to

$$my_{11}\Omega^2-1=0 \quad . \quad . \quad . \quad . \quad . \quad (25)$$

and equation (24) becomes

$$mc\Delta\Omega^4-(c\phi_{11}-my_{11})\Omega^2-1=0 \quad . \quad . \quad . \quad . \quad (26)$$

Under such circumstances the equation

$$\Omega^2=1/my_{11} \quad . \quad . \quad . \quad . \quad . \quad (27)$$

gives the maximum safe speed for a two-bladed airscrew.

It will be observed that equation (27) is independent of the inertia of the airscrew and so all two-bladed airscrews of the same weight will have the same maximum safe speed.

To take a definite case. Let

$$W=48 \text{ lbs.}$$

and

$$A=C=31{,}488 \text{ lbs. ins.}^4$$

So that

$$m=\tfrac{1}{8}$$
$$a=c=80 \text{ approx.}$$

With the same airscrew shaft as before we find that equation (27) gives the lower whirling speed as

10,800 r.p.m.

and this will be the highest speed at which the airscrew could be safely run in any circumstances.

The other whirling speed given by equation (26) is found to be

23,400 r.p.m.

With $a=c$ and $b=0$

$$a_1=b_1=a/2=c/2$$

and equation (22) becomes

$$\begin{aligned}&\{[my_{11}p^2-1][ma_1\Delta(2\Omega-p)^2-a_1\phi_{11}]\\&+[my_{11}(2\Omega-p)^2-1][ma_1\Delta p^2-a_1\phi_{11}]\}p(2\Omega-p)\\&+[my_{11}p^2-1][my_{11}(2\Omega-p)^2-1]=0 \quad . \quad . \quad . \quad (28)\end{aligned}$$

To obtain the resonant speeds from the gear action we put $p=\pm 12\Omega$ in equation (28).

For $p=12\Omega$ we obtain resonant speeds in the neighbourhoods of

165, 960 and 2,280 r.p.m.

and for $p=-12\Omega$ resonant speeds at about

150, 840 and 1,920 r.p.m.

For resonant speeds from blade interference we put $p=\pm 2\Omega$ in equation (28). With $p=2\Omega$ equation (28) reduces to

$$4my_{11}\Omega^2-1=0 \quad . \quad . \quad . \quad . \quad . \quad (29)$$

which gives a resonant speed at half the lowest whirling speed or half the maximum safe speed of the airscrew.

In the particular case considered this will be about

5,400 r.p.m.

Finally we put $p=-2\Omega$ in equation (28) and we obtain resonant speeds in the neighbourhoods of

660, 3,340 and 10,400 r.p.m.

Hence we arrive at the conclusion that for the two-bladed airscrew there is danger of failure resulting from the gear action.

Thus in both cases the dimensions of the system are unsuitable. For the four-bladed airscrew resonance occurs in the useful range of speed through blade interference and in the case of the two-bladed airscrew through gear action.

In the foregoing we have supposed that the blades of the airscrew were rigid. But we know that in general the blades of an airscrew are appreciably flexible, certainly about the lateral axis, the vibration about which is commonly known as "flutter." This flexibility may possibly have an appreciable effect on the periods of vibration of a system of which an airscrew forms part. Owing to the complexity of the section of an airscrew blade it would prove extremely difficult to estimate its flexibility by mathematical analysis. The writer in his paper on the "Stability of Aero Engines" in the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY for April, 1923, has investigated this problem and has shown that it is possible to replace the blades by flexible arms carrying tip loads. For a proper solution of the main problem under consideration the flexibility of the blades should be taken into account.